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IN THIS issue

Motivation and Attitude of Preservice Elementary Teachers toward Mathematics

Christine A. Perry

This study investigated preservice elementary teachers' achievement goal orientations for learning mathematics and the relationship of those goals to their attitudes toward mathematics. Self-report instruments were administered to assess three achievement goals—mastery, performance-approach, and performance-avoid, and three constructs of attitude—confidence in learning mathematics, usefulness of mathematics, and mathematics as a male domain. The preservice teachers were higher in mastery goals than in performance goals, and performance-avoid goals were higher than performance-approach goals. Mastery goals correlated positively to all three constructs of attitude. Since mathematics classes are traditionally performance-oriented, these results suggest a mismatch between personal and classroom goals that could result in negative attitudes and the adoption of maladaptive performance-avoid goals. These findings suggest that mathematics content courses for preservice elementary teachers should be taught in a classroom climate that supports and encourages mastery goals.

Apprenticeship of Immersion: College Access for High School Students Interested in Teaching Mathematics or Science

Shelly Sheats Harkness, Iris DeLoach Johnson, Billy Hensley, James A. Stallworth

Research has shown that prediction has the potential to promote the teaching and learning of mathematics because it can be used to enhance students' thinking and reasoning at all grade levels in various topics. This paper addresses the effectiveness of using prediction on students' understanding and reasoning of mathematical concepts in a middle school algebra context. In the treatment classroom prediction questions were utilized at the launch of each algebra lesson, and in the control classroom such questions were not used. Both classrooms were taught by the same teacher and used the same curriculum. After completing each of the linear and exponential units, the two classrooms were compared in terms of their mathematical understanding and reasoning through unit assessments. Overall, the treatment classroom outperformed the control classroom on the unit assessments. This result supports that prediction is a valid construct with respect to enhanced conceptual understanding and mathematical reasoning.

Using Prediction to Promote Mathematical Understanding and Reasoning

Lisa Kasmer, Ok-Kyeong Kim

Issues related to college access and the need for a pipeline of STEM teachers provided the impetus for the Ohio Board of Regents (OBR) to issue a call for Ohio universities to design precollege experiences for high school students with three major goals in mind: (a) improvement in mathematics, science, or foreign language learning; (b) increased attraction to careers as teachers of these subjects; and, (c) increased familiarity and readiness for college admission to study these subjects. Through funding provided by an OBR grant the authors designed and implemented a summer immersion program for high school juniors and seniors in order to meet the needs of this call. Students with self-reported interests in teaching mathematics or science spent two weeks on two environmentally different universities, Miami University and the University of Cincinnati, as a means to expose them to different campus climates while building a greater sense of belonging, both culturally and academically. They also earned three PreCalculus credits through rigorous college-coursework. This paper describes the program, reports pre- and post-test data analyses, provides insights into students' perceptions of the college experience, and reflects on the authors' own lessons learned.

Motivation and Attitude of Preservice Elementary Teachers toward Mathematics

Christine A. Perry
Morehead State University

This study investigated preservice elementary teachers' achievement goal orientations for learning mathematics and the relationship of those goals to their attitudes toward mathematics. Self-report instruments were administered to assess three achievement goals—mastery, performance-approach, and performance-avoid, and three constructs of attitude—confidence in learning mathematics, usefulness of mathematics, and mathematics as a male domain. The preservice teachers were higher in mastery goals than in performance goals, and performance-avoid goals were higher than performance-approach goals. Mastery goals correlated positively to all three constructs of attitude. Since mathematics classes are traditionally performance-oriented, these results suggest a mismatch between personal and classroom goals that could result in negative attitudes and the adoption of maladaptive performance-avoid goals. These findings suggest that mathematics content courses for preservice elementary teachers should be taught in a classroom climate that supports and encourages mastery goals.

Meeting the challenges of mathematics reform as outlined by the National Council of Teachers of Mathematics (NCTM, 1989, 1991, 2000), the Conference Board of the Mathematical Sciences (CBMS, 2001), and the No Child Left Behind Act of 2001 (2006) will require that we engage or motivate more students to learn more mathematics at deeper levels. While the construct of motivation is of considerable concern to education professionals in general, it is particularly important in the mathematics classroom (Grouws & Lembke, 1996; Kloosterman & Gorman, 1990; Middleton, 1992). In fact, many psychologists choose to situate motivation research specifically in the mathematics classroom, because the characteristics of many mathematics classrooms appear to facilitate maladaptive patterns of motivation (Ryan & Patrick, 2001; Turner et al., 1998).

Students' motivation and attitudes toward mathematics develop early and are strongly influenced by teacher actions and attitudes (Karp, 1988, 1991; Middleton & Spanias, 1999). Students pick up unintended messages from teachers about what it means to know and do mathematics (Karp, 1988, 1991; Kloosterman, Raymond, & Emenaker, 1996). Some studies suggest that students learn to like or dislike this subject (Meece, Wigfield, & Eccles, 1990; Midgley, Feldlaufer, & Eccles, 1989). Also, teachers' ideas about what motivates students play a major role in the instructional activities they choose (Middleton, 1992).

In this article, I report on a study of the relationship between the motivation to learn mathematics and attitude toward mathematics of preservice elementary teachers. These college students are both students of mathematics and future mathematics teachers. Their motivation has implications for their own learning of the content (Barron, Harackiewicz, & Tauer, 2001; Urdan, Pajares, & Lapin, 1997), and mastery of content knowledge affects their future teaching of this subject (Ball, Lubienski, & Mewborn, 2001; Ma, 1999).

Meyer (1980) claimed that in addition to poor content knowledge, many elementary teachers have negative attitudes toward mathematics. Poor attitudes may also adversely affect a teacher's instructional practices (Karp, 1988, 1991). According to Wilkins (2002), more reform-oriented instruction occurs in classrooms where teachers have positive attitudes towards mathematics, and these teachers are more likely to develop positive attitudes in their students (Banks, 1964). NCTM (1989, 1991, 2000) has recognized the importance of developing positive student attitudes toward mathematics.

Theoretical Background

Motivation

Educators are generally interested in a type of motivation referred to as achievement motivation (Dweck & Elliott, 1983). Achievement motivation is dependent on one's goals related to competence. A student's goal may be to gain competence in some area or it may be to achieve a favorable judgment of competence. Some students may seek to avoid unfavorable judgments as their main goal.

Achievement goals may be classified as either mastery or performance. Students with mastery goals

want to gain competence (Ames & Archer, 1988; Turner et al., 2002). Their goal is to actually learn the content, and classrooms oriented to this goal will encourage students to master tasks and develop intellectually. Success from this perspective is attained through effort. The goal of performance-oriented students is some objective other than learning, such as winning a prize or getting high grades. These objectives are external to gaining knowledge (Lepper, 1988). Classrooms geared to this orientation are competitive and emphasize grades. The primary difference in these two types of goal orientations is whether learning is valued as an end in itself (mastery), or if learning is just a means to reach some external goal (performance) (Meece, Blumenfeld, & Hoyle, 1988).

Performance goals may be further divided into two distinct categories labeled performance-approach and performance-avoid goals (Dweck & Elliott, 1983). Students with performance-approach goals seek favorable judgments of their competence, whereas students with performance-avoid goals seek to prevent unfavorable judgments of their ability. Urdan et al. (1997) proposed that a lack of separation between these two dimensions of performance goals resulted in the weak relationships among performance goals and other variables found by some researchers. The study presented in this article utilized the trichotomous framework of goal theory and investigated the mastery, performance-approach, and performance-avoid goals of elementary preservice teachers.

Attitude

Fishbein and Ajzen (1975) presented a conceptual framework that used beliefs as the fundamental building blocks of attitude. They contend that a person's attitude is a function of their beliefs. Beliefs represent the information one has accumulated through past experience with the object. Therefore, as individuals accumulate beliefs about a specific object, they form an attitude toward that object at the same time. This theory implies that attitude toward mathematics is a result of one's past experiences with mathematics and the salient beliefs that have developed through those experiences.

Mastery-oriented and performance-oriented students have different beliefs. For example, mastery-oriented students believe that failure is due to lack of effort, but performance-oriented students believe that failure is due to lack of ability (Diener & Dweck, 1978). Therefore, a student's goal orientation may have an effect on their attitude toward mathematics.

Purpose and Research Questions

Teachers frequently model their mathematics teaching after their own former high school and elementary teachers, and these models of instruction are often substandard (Ball et al., 2001; Brown & Smith, 1997; Middleton, 1992). Unfortunately, university coursework does little to change beliefs shaped by 13+ years of firsthand experience as students in mathematics classrooms (Ball et al.; Foss & Kleinsasser, 1996). In addition, Hiebert et al. (2002) noted that teachers seldom turn to research to guide their teaching practice. The hours of observations one accumulates as a student instill a view of teaching that is exceedingly difficult to change (Ball, 1988; Taylor, 2002).

Preservice elementary teachers have spent many hours as students in mathematics classes using traditional instructional approaches (Ball, 1988) that tend to favor males (Fennema, 2000). Traditional instruction in mathematics is performance-oriented and encourages the adoption of performance goals (Anderman, Maehr, & Midgley, 1999; Nicholls, Cobb, Wood, Yackel, & Patashnick, 1990). However, results of some research suggest that females are more mastery-oriented than males (Elliot & Church, 1997; Peterson & Fennema, 1985). Since most preservice elementary teachers are female, this traditional, performance-oriented instruction coupled with an initial inclination to mastery goals may negatively affect the attitude they present toward mathematics in their own classrooms and encourage the adoption of maladaptive performance goals by students in the mathematics classes they teach. Thus, there is a cycle of female elementary teachers with negative attitudes toward mathematics unwittingly teaching this subject in the same traditional performance-oriented manner they were taught. As a result, these negative attitudes and performance goals in mathematics classes are passed on to mastery-oriented young girls who are the future female elementary teachers. This "hidden" cycle is particularly deleterious.

The focus of the research reported in this article was to describe the types of achievement goals adopted by preservice elementary teachers with respect to instruction in mathematics. This study also investigated the relationship between the types of goals that they adopt and their attitudes toward mathematics. The following research questions were addressed.

1. What are the levels of achievement goal orientations—mastery goal orientation, performance-

approach goal orientation, and performance-avoid goal orientation—for learning mathematics for preservice elementary teachers?

2. What are the attitudes of preservice elementary teachers toward mathematics as revealed by three measures of attitude: confidence in learning mathematics, usefulness of mathematics, and mathematics as a male domain?

3. What relationships exist, if any, among three measures of achievement goal orientation and three measures of attitude toward mathematics for preservice elementary teachers?

Methodology

Sample

The participants in this study were a sample of convenience taken from the population of students enrolled in the first mathematics content course required for a program leading to certification in elementary education at institutions of higher education. There were 384 participants from four state universities in the southeast region of the United States. The preservice teachers were predominantly female (88.5%) and most were sophomores and juniors (76.6%). Their ages ranged from 18 to 56 with a mean age of 22.

Instruments

The participants completed a background questionnaire to provide personal data and a survey designed to measure their achievement goals and attitude toward mathematics. The survey consisted of six scales from established instruments: three designed to measure achievement goal orientation and three developed to measure constructs of attitude toward mathematics. The scales contained statements that the participants ranked on a Likert scale from one to five based on their level of disagreement or agreement with the statement.

The scales used to measure achievement goals were selected from a set of subscales called the Patterns of Adapted Learning Scales (PALS) (Midgley et al., 2000). This research used the following scales: Mastery Goal Orientation (Revised), Performance-Approach Goal Orientation (Revised), and Performance-Avoid Orientation (Revised). The PALS instrument is widely used by many motivation researchers at various grade levels (Anderman et al., 1999; Ryan & Patrick, 2001; Turner et al., 2002), but none of these studies used college students as subjects. Therefore the wording of some of the items was changed slightly to make the statements more appropriate for college students. For example, "teacher" was changed to "professor."

The three scales measuring attitudes were subscales from the Fennema–Sherman Mathematics Attitude Scales (Fennema & Sherman, 1976b). The subscales used in this research were the Confidence in Learning Mathematics Scale, the Mathematics as a Male Domain Scale, and the Mathematics Usefulness Scale.

Procedures

To enlist participants, the cooperation of professors and instructors teaching the course, Mathematics for Elementary Teachers I, was first solicited. Once this cooperation was secured, the researcher scheduled a visit to the classroom to enlist the students as participants and administer the instruments. All classroom visits were made during the first two weeks of the fall semester in 2006.

Results

Reliability Analysis

A reliability analysis was performed on each of the six subscales. The results of this analysis are shown in Table 1.

After the reliability analysis, participants who indicated they were in a program other than elementary or special education were filtered out of the sample. This reduction left a sample size of 340. The research questions were addressed by an analysis of this reduced sample; however, the actual value of n for any given item may vary due to non-responses on some of the survey questions.

Research Question 1. What are the levels of achievement goal orientations—mastery goal orientation, performance-approach goal orientation, and performance-avoid goal orientation—for learning mathematics for preservice elementary teachers?

Table 2 displays the means and standard deviations for the subscales used to measure the three achievement goal orientations. Results revealed that for these preservice elementary teachers, the means are highest for mastery goals, followed by performance-avoid goals. The lowest mean was in performance-approach goals.

A repeated measures analysis of variance (ANOVA) performed on these means revealed statistically significant results, Hotelling's Trace = 2.965, $F(2, 336) = 498.176$, $p < .05$. Pairwise comparisons were then made using paired samples t-tests. A Bonferroni-corrected alpha level was used to prevent inflation of

Table 1
Reliability Coefficients for Scales

Scale	Number of Items	Cronbach's Alpha Coefficient	*n*
PALS			
Mastery	5	.883	381
Performance-approach	5	.875	378
Performance-avoid	4	.821	382
Fennema-Sherman			
Confidence	12	.956	375
Male domain	12	.771	375
Usefulness	12	.887	377

Table 2
Descriptive Statistics for PALS Achievement Goal Orientation Scales

Scale	M	SD	*n*
Achievement Goal Orientation			
Mastery	4.274	.685	338
Performance-approach	2.409	.895	338
Performance-avoid	2.711	.959	338

Type I error due to three *t*-tests performed. The results of this analysis revealed statistically significant differences between each pair of means ($p < .05$). Cohen's *d* was calculated to determine the effect size for each paired samples *t*-test. Table 3 summarizes these results.

Research Question 2. What are the attitudes of preservice elementary teachers toward mathematics as revealed by three measures of attitude: confidence in learning mathematics, usefulness of mathematics, and mathematics as a male domain?

It was hypothesized that, compared with published data on the Fennema–Sherman instrument, preservice teachers in this study would demonstrate low confidence, a tendency to see mathematics as a male domain, and indicate that they did not perceive mathematics as useful. Thus, a comparative sample of subjects who had previously completed the Fennema–Sherman scales was needed. The sample from a study by Eckard (1995) was selected for use as a comparison group. This study investigated the attitudes toward mathematics of 153 college women enrolled in general studies classes. Since the sample for the present study is predominantly college women, such a female comparison group was desirable. Additionally, the Eckard study provided a sample that included women pursuing a variety of programs of study, making it an appropriate group with which to compare a sample of preservice elementary teachers in order to examine possible differences. Table 4 reveals the means for the attitude subscales from both studies.

One sample *t*-tests were performed using the mean scores from the Eckard (1995) study as comparative values. A statistically significant difference was found on Confidence in Learning Mathematics ($p < .001$), suggesting that this sample of preservice elementary teachers had less confidence in learning mathematics than the female college students of various majors in the study by Eckard. There were no significant differences in the means for the Mathematics as a Male Domain and Usefulness of Mathematics subscales. The results of the *t*-tests are shown in Table 4.

Research Question 3. What relationships exist, if any, among three measures of achievement goal orientation and three measures of attitude toward mathematics for preservice elementary teachers?

To examine the relationships among the six variables, Pearson correlation coefficients were computed. Table 5 displays these correlations.

The table reveals several weak to moderate relationships among the achievement goal orientation and attitude variables. All three constructs of attitude were positively correlated with each other and with a mastery goal orientation. There was also a strong

Table 3
Paired Samples t-Test Results for Comparisons of PALS Scales

Pair	Mean Difference	SD	*t*	*p* (2-tailed)	Cohen's *d*
Mastery/Performance-approach	1.866	1.086	31.580	.000	1.718
Mastery/Performance-avoid	1.564	1.158	24.816	.000	1.350
Performance-app/Performance-avoid	–.302	.692	–8.026	.000	.437

Table 4
Comparative Statistics on Preservice Teachers and Female College Students from Eckard (1995)

Fennema–Sherman Attitide Scale	Preservice Teachers ($n = 340$)		Eckard Study ($n = 153$)		*t*	*p* (2-tailed)
	M	SD	*M*	*SD*		
Confidence	40.30	12.35	43.24	12.49	–4.39	.00
Male domain	54.13	5.20	54.10	5.12	.12	.91
Usefulness	49.23	7.64	48.52	8.51	1.71	.09

Table 5
Correlations Among the Subscales for Achievement Goal Orientations and Attitudes

Subscale	1	2	3	4	5	6
1. Mastery	1	.073	.035	.247**	.404**	.581**
2. Performance-approach	—	1	.724**	.121*	–.093	.088
3. Performance-avoid	—	—	1	–.045	–.068	.002
4. Confidence	—	—	—	1	.269**	.523**
5. Mathematics as a male domain	—	—	—	—	1	.371**
6. Usefulness	—	—	—	—	—	1

*$p < .05$, two-tailed; **$p < .01$, two-tailed.

positive correlation between performance-avoid and performance-approach goals ($r = .724$, $p < .01$).

As hypothesized, there was a significant positive correlation between mastery goal orientation and confidence in learning mathematics ($r = .247$, $p < .01$). There was also a significant positive correlation between mastery goals and the mathematics as a male domain variable ($r = .404$, $p < .01$). On the mathematics as a male domain subscale, a high mean indicates a view that mathematics is not a subject just for males. Therefore, this positive correlation means that a mastery goal orientation correlated positively with the view that mathematics is not a subject just for males. The correlation analysis also indicates a significant positive correlation between mastery goals and the usefulness of mathematics variable ($r = .581$, $p < .01$).

Discussion

Goal Orientations

For the preservice elementary teachers surveyed in this study, an orientation to mastery goals dominated. This result supports the findings of previous research that females tended to be mastery-oriented (Elliot & Church, 1997; Fennema, 2000; Peterson & Fennema, 1985).

Persons who adopt mastery goals seek to increase their competence (Dweck & Elliott, 1983). Their goal is to acquire knowledge and develop new skills. They value the process of learning and believe that success will come with effort (Ames & Archer, 1988). Barron and Harackiewicz (2001) and Barron et al. (2001) reported that mastery-oriented college students described greater interest in subject content. Researchers have consistently found positive relationships between mastery goals and intrinsic motivation (Ames & Archer; Archer, 1994). That the preservice elementary teachers in this study were high in mastery goals for mathematics is encouraging, because it implies that these future teachers were concerned with mastering the content they will one day teach.

Since mastery goals are generally considered best for learning, the result that mastery goals were high and performance goals of both types were relatively low reflect a positive finding. Performance goals have been associated with maladaptive patterns of learning (Ames, 1992; Ames & Archer, 1988; Archer, 1994); however, some researchers have attributed the negative outcomes of performance goals to the avoidance category (Elliot & Church, 1997; Middleton & Midgley, 1997). Elliot and Church concluded that the ideal pattern of goals would be the adoption of both mastery and performance-approach goals combined with a lack of performance-avoid goals.

Preservice teachers in the present study reported a significantly higher level of performance-avoid goals than performance-approach goals. Additionally, the level of mastery goals was significantly higher than the level of performance-avoid goals. This combination of high mastery goals combined with performance-avoid goals that were significantly higher than performance-approach goals is far from ideal as described by Elliot and Church (1997).

If the pattern of goals found by this study is typical of preservice elementary teachers, then higher levels of performance-avoid goals may explain preservice elementary teachers' poor performance in mathematics content courses despite their high level of mastery goals. Many researchers reported detrimental effects of adopting performance-avoid goals (Elliot & Church, 1997; Middleton & Midgley, 1997). These effects included reduced intrinsic motivation, poorer graded performance, reduced task involvement, lower self-efficacy, higher test anxiety, and a tendency to avoid seeking help. Perhaps the mismatch between the personal mastery goals of some students and the performance-oriented instruction typically provided in a traditional mathematics classroom results in the adoption of maladaptive performance-avoid goals by students who are mastery-oriented.

Attitudes

Previous research indicates that females tend to have less confidence than males in learning mathematics (Fennema & Sherman, 1976a, 1978; Iben, 1991). The analysis of data in the current study revealed that a predominantly female sample of preservice elementary teachers reported significantly less confidence in learning mathematics than a sample of female college students from a variety of other majors (Eckard, 1995). This finding suggests that those who choose elementary education as their field of study are on the low end of confidence levels within a group (females) who are already identified as low in confidence.

That preservice elementary teachers have low confidence in learning mathematics is not encouraging. Teachers with negative attitudes tend to teach mathematics in a performance-oriented style, which leads some of their students to develop low confidence also (Karp, 1988, 1991). These teachers utilize limiting instructional strategies, such as focusing on memorized procedures, relying on textbooks, and insisting on finding one right answer. Ma (1999) noted that among the elementary teachers she observed, "Not a single teacher . . . would promote learning beyond his or her own mathematical knowledge" (p. 54). Therefore, it seems that ineffective mathematics instruction continues a legacy of inadequacy in mathematics content knowledge to another generation of students, continuing the cycle of poor attitudes and insufficient learning.

Attitudes and Goal Orientations

The preservice teachers in this study revealed a combination of high levels of mastery goals for learning mathematics with low levels of confidence. According to O'Neal, Ernest, McLean, and Templeton (1988), the Fennema-Sherman Confidence in Learning Mathematics Scale and the Mathematics Anxiety Scale appear to measure the same trait. If this is the case, then the low level of confidence reported by preservice teachers is also indicative of mathematics anxiety. According to Harackiewicz and Elliot (1993), mastery-oriented students in performance-oriented classrooms experience anxiety. Since mathematics classes are traditionally performance-oriented, the results of this research support the conclusions of

Harackiewicz and Elliot. These results provide some evidence that a mismatch between the personal achievement goals of students and the classroom goal orientation result in lower confidence in learning mathematics and therefore, higher levels of mathematics anxiety.

The positive correlations between a mastery goal orientation and all three constructs of attitude are promising findings for those interested in promoting reform instruction in mathematics classrooms. According to Stipek et al. (1998) there was considerable alignment between instruction that promoted mastery goals in students and the type of mathematics instruction called for by NCTM. Quinn (2001) found that a mathematics methods course based on NCTM *Standards* could improve preservice teacher attitudes toward mathematics. It appears that by teaching in a manner consistent with the NCTM *Standards*, teachers can foster a mastery goal orientation in their students and improve their attitudes toward mathematics as well.

Conclusion

The foundation of this research study was to seek, through an investigation of achievement goal orientations, a possible cause of the deleterious cycle of poor mathematics teaching and negative attitudes toward mathematics unwittingly passed from one generation to the next by elementary teachers. This study found that preservice elementary teachers reported a high level of mastery goals in their mathematics content course. Since mathematics classes are traditionally performance-oriented, this situation presents a mismatch between the predominant goal adopted by these students and traditional mathematics classes. This mismatch could result in negative attitudes toward mathematics and the adoption of maladaptive performance-avoid goals.

Since motivation researchers generally consider mastery goals best for learning (Ames & Archer, 1988; Elliot & Church, 1997; Middleton & Midgley, 1997), attempting to change the goal orientation of the preservice teachers is not recommended. A better solution is to change the motivational climate of the mathematics classroom to one that supports and encourages mastery goals. The characteristics of such a classroom align with the practices suggested by the NCTM (1989, 1991, 2000), and the Conference Board of the Mathematical Sciences in the report *The Mathematical Education of Teachers* (CBMS, 2001). The correlation between mastery goals and positive attitudes toward mathematics found by this study suggests that teaching mathematics in a mastery oriented classroom may improve the attitudes of these future teachers and therefore increase the likelihood that they will become lifelong learners of mathematics. Preservice elementary teachers instructed in this manner will take positive attitudes toward mathematics to their future classrooms, as well as a model of mathematics teaching that centers on student learning. In doing so, they will break the cycle of passing on negative attitudes and strategies for mathematics teaching that may promote maladaptive performance-avoid goals. With this cycle broken, we can meet the challenge of rising expectations for K-12 mathematics education.

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Apprenticeship of Immersion: College Access for High School Students Interested in Teaching Mathematics or Science

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Issues related to college access and the need for a pipeline of STEM teachers, provided the impetus for the Ohio Board of Regents (OBR) to issue a call for Ohio universities to design pre-college experiences for high school students with three major goals in mind: (a) improvement in mathematics, science, or foreign language learning; (b) increased attraction to careers as teachers of these subjects; and (c) increased familiarity and readiness for college admission to study these subjects. Through funding provided by an OBR grant we designed and implemented a summer immersion program for high school juniors and seniors in order to meet the needs of this call. Students with self-reported interests in teaching mathematics or science spent two weeks on two environmentally different universities, Miami University and the University of Cincinnati, as a means to expose them to different campus climates while building a greater since of belonging, both culturally and academically. They also earned three PreCalculus credits through rigorous college-coursework. Within this manuscript we describe the program, report pre- and post-test data analyses, provide insights into students' perceptions of the college experience, and reflect on our own lessons learned.

It seems difficult to imagine that more than 25 years have passed since the *Nation at Risk* (National Commission on Excellence in Education, 1983) report was published as an urgent call to action for educational reform. Actions by national and state government agencies quickly got underway to address many of the issues presented in that report. Federal and state governments set aside funds specifically to support reform in mathematics and science: professional development for teachers, curriculum for classrooms, investigation of ways that students learn, and technology and materials to support best practices. Although there is evidence that some improvements have been made (NCES, 2007), it is clear that we are still "awash in anxiety about mathematics education" (Steen, 2007, p. 2).

Reports from various sources (Berry & Bol, 2005; BHEF, 2007; COSEPUP, 2007; U.S. Department of Education, 2006) point to concern about the achievement gaps in mathematics and science in the United States and the overall dismal performance of our mathematics students. These collective concerns continue to fuel impetus to fund various educational programs such as: science, technology, engineering, and mathematics (STEM) camps; research apprenticeship programs; and, academic year enrichment and support programs. Such programs are typically designed to improve students' understanding of mathematics concepts, the images of themselves as STEM learners, and their overall knowledge and interest in STEM careers. Additional goals support the realization of access to higher learning for students who have been able to perform sufficiently well at the high school level. Pursuant to these same goals, the Ohio Board of Regents issued a call for Ohio universities to design pre-college experiences for high school students with three major goals in mind: (a) improvement in mathematics, science, or foreign language learning for all students in the state; (b) increased attraction to careers as teachers of these subjects; and (c) increased

familiarity and readiness for college admission to study these subjects.

Literature Review

Issues relating to college access are viewed as a critical challenge facing post-secondary institutions (Heller, 2001, 2002). There are several policy reports that have examined this challenge and many have suggested various policies to increase access to higher education, especially among students traditionally under-represented (Advisory Council on Student Financial Aid [ACSFA], 2001, 2002; NCPPHE, 2002). According to *Access Denied*, a report prepared by the ACSFA (2001), between 1970 and 1997 the college participation rate of upper-income students increased by more than 20% as compared with only a 5% increase in the participation rate of low-income students. As a result, college access has spawned broad scholarly consideration as this trend has become increasingly more apparent.

The research literature identifies a student's socio-economic status (SES) and race or ethnicity as the most common obstacles to college access. Freeman (1997), speaking about race, finds that African American students perceive significant economic and psychological barriers to participation in higher education. As such, race and SES often intersect in their impact on college access. Perna and Titus (2005) found racial differences in the effect of parental involvement on college enrollment with African American and Hispanic students possessing fewer forms of social and cultural capital that promote college access. In addition to parental involvement, family income is another aspect of SES that poses a substantial obstacle to college access. For instance, McDonough's (1997) study finds that students with similar school achievement and economic backgrounds make consistently similar college decisions, as compared with students with analogous academic credentials and different social class; simply, those students that have a closely tied economic experience choose similar post-secondary paths.

In two recent studies considering the impact of state public policies on the racial and ethnic stratification of college access and choice, both an empirical study (Perna & Titus, 2004) and a single case study (Perna, Steele, Woda, & Hibbert, 2005) found that racial gaps in college access and enrollment persist. There are also reports available that offer possible national policy solutions linked to federal financial aid as a means to increase access and choice for low income students (Institute for Higher Education Policy [IHEP], 2002; St. John et al., 2004).

The role of post-secondary institutions in transforming social inequalities has long been a subject in the study of higher education (Bourdieu & Passeron, 1977, 1979; Giroux, 1983). Since college access, enrollment, and student success have much bearing on state and local communities, many researchers are beginning to identify the gaps between entering students' expectations and their levels of engagement in the first year of college so that institutions can target their efforts to create educationally effective programs for new students (Miller, Bender, & Schuh, 2005; Upcraft, Gardner, & Barefoot, 2005). For example, when faculty members emphasize educational practices such as writing, active and collaborative learning, or using diverse perspectives to understand issues, students are more likely to engage in these activities (Kuh, Nelson Laird, & Umbach, 2004). As a result, the fulfillment of students' academic and social expectations of college has been linked positively to the social integration at institutions (Braxton, Vesper, & Hossler, 1995; Helland, Stallings, & Braxton, 2001–2002).

Both student involvement behaviors and perceptions of integration play a role in persistence decisions (Berger & Milem, 1999; Milem & Berger, 1997). Specifically, Berger and Milem found that first-year students who reported more involvement behaviors reported higher academic and social integration as well as more associational dedication. Similarly, Bean's (1985) student persistence model identified academic, social-psychological, and environmental factors as dynamics likely to affect the socialization of students' sense of belonging. A study by Hausmann, Schofield, and Woods (2007) indicated that students who described more peer-group interactions, interactions with faculty, and peer support reported having a greater sense of belonging on the college campus.

It was with the intent to create these opportunities for belonging and connection that we applied for and received an Ohio Board of Regents STEM Education grant to work with high school students who were considering STEM teaching as a profession. Our program focused on an immersion into the college campus culture at two environmentally different universities as a means to expose students to different campus climates while building a greater sense of belonging—both culturally and academically.

Southwest Ohio Secondary Teachers Academy

Year 1

During the first year of the Southwest Ohio Secondary Teachers Academy (*SOSTA*) we attempted to recruit 50 high school students who would be entering their junior or senior years in the fall of 2007. We focused our recruitment efforts on two area high schools (Schools A and B), the schools that we partnered with to write the grant proposal. These high schools were from different districts and had diverse student populations (see Table 1). Please note that these numbers are approximations based on website searches for demographic data.

The *SOSTA* student application included several components to be completed by students, school guidance counselors, teachers, and parents/guardians. Students were asked to answer two questions: (a) Why are you interested in this program and being a math teacher? (b) What experiences might have led you to aspiring to be a math teacher?

Guidance counselors were asked to complete a section that requested components of each student's academic and behavioral profile: overall grade point average (GPA); mathematics coursework and grades in those courses; Ohio Graduation Test scores and any other standardized test scores; documentation of behavior referrals; and attendance data. Teachers of the student applicants were also asked to write a statement and address the following: (a) Why do you believe that this student will be academically and personally successful in this program? (b) Please discuss work ethic, student relations, and academic progress.

Table 1
Demographics Comparison of Schools A and B

	School A	School B
Enrollment	1,200	1,900
Ethnicity		
Asian	1%	2%
Hispanic	NA	3%
Black	92%	53%
White	4%	39%
Unknown	3%	3%
Free/reduced lunch	66%	32%

NA, not applicable.

The final written statement was to be completed by a parent or guardian and asked: (a) Why do you believe your child should be in this program? (b) How will you support your child to ensure her/his successful completion of this program?

The last page of the application form provided a Statement of Understanding which outlined requirements and expectations. The students and their parents or guardians were required to sign the Statement to acknowledge their agreement and intent to comply. A committee of teachers and university partners met to review the applications. This committee accepted students who had GPAs above 2.0 and few or no discipline referrals. Forty-four students, which included 26 students from schools other than Schools A and B, were accepted into the program. Students, their parents or guardians, teachers, and university faculty attended an Orientation Meeting in May. At this meeting we focused on explaining the program, answering questions, and asking parents and guardians to sign numerous forms.

An integral component of the *SOSTA* program incorporated a 14-day immersion on both campuses. The students spent the first weekend and week on Miami University's (MU) campus and the second weekend and week on the University of Cincinnati's (UC) campus, transported by bus to and from the campuses. Monday-Friday they were immersed in a *PreCalculus* course labeled as a Transfer Assurance Guidance (TAG) course. In 2005, The Ohio Board of Regents formally reviewed and approved TAG courses (http://regents.ohio.gov/transfer/tagcourses/tag.php) and guaranteed the courses and their credits would "transfer and apply" at any of Ohio's higher education institutions. In addition to the opportunity to earn TAG course credits, students were given graphing calculators and textbooks at no charge. Additionally, we anticipated that some students needed summer income to support themselves and/or their families, and we therefore designated grant money for student stipends in the amount of $1,000. *SOSTA* students could earn this amount by completing both the summer component and the academic-year Saturday Sessions.

Each morning from 9:00 AM to 12:00 PM students attended lecture. The term lecture is used loosely here to refer to a large-group setting; however, there were interactions between the students and the instructor, the students worked together in pairs, and, at times, they participated in data-gathering or whole-group activities. Each afternoon, from 1:00 PM to 3:00 PM,

the students worked in small groups to make sense of the morning lecture topics. The small groups had a typical teacher-to-student ratio of about 1:7. Evenings and weekends were devoted to campus activities such as: workouts at the campus recreation centers; bowling; attending movies; and study sessions for completing homework.

During the 2007–2008 academic year, following the summer immersion, we scheduled 10 Saturday Sessions—about one per month. These sessions lasted three hours and focused on additional mathematics coursework and dissemination of college admission advice, SAT and ACT preparation, and financial aid information. On the final Saturday Session in May we hosted a celebration banquet and invited parents, siblings, teachers and all others involved in implementing the *SOSTA*.

The first year served as a pilot experience for our future *SOSTA* efforts. We did not formally collect data in the form of pre- and post-tests or surveys. However, lessons we learned during the first year were taken into consideration as we planned the *SOSTA* for the following year. One lesson learned centered on a criticism from students regarding the length and intensity of the program. Students indicated that they felt they were constantly busy and often exhausted. They wanted fewer extra-curricular activities in the evenings during the summer immersion and more time to study and work on homework. Students also indicated that the monthly Saturday Sessions during the academic year often conflicted with their extra-curricular academic year activities as well as opportunities to work. Despite these complaints, all 44 students completed the program. With lessons learned in mind, and a second grant for the 2008–2009 academic year, we began planning for Year 2.

Year 2

We used the same recruitment process for Year 2 that was used for Year 1; however, the timing of notification was delayed because of state budget issues. These budget issues required us to offer student stipends in the amount of $800, rather than $1,000. Additionally, receiving notification in March 2008 created a time-crunch for us as we began contacting schools and planning the summer program. Again, we accepted 44 students.

Based on lessons learned from Year 1, as mentioned above, we decided to spread the summer immersion across the months of June, July, and August. During the month of June, students spent a week on MU's campus, in July they participated in two Saturday Sessions at one of the partner high schools and in August they spent a week on UC's campus. We anticipated that this schedule would make the program less intense and more manageable for students. We also anticipated that this would allow us to assign more projects with due dates on the Saturday Sessions and the first day at UC in August. During the on-campus weeks we scheduled fewer evening activities in order to give students more time to work collaboratively on homework assignments and projects and to study for quizzes and exams. We also reduced the number of academic year Saturday Sessions from 10 sessions to five: the two in July, one in September (SAT and ACT preparation), one in October (college admission and financial aid planning), and a December Celebration Dinner.

Additionally, we invited five students from the 2007–2008 cohort of *SOSTA* to participate as Alumni Mentors. We purposefully selected five students who were *not* our top academically performing students. We believed that these moderately successful students would serve as good role models for hard work and might also personally benefit in at least three ways: gaining experience in serving in leadership roles; learning pre-calculus content more deeply by assisting others; and achieving a feeling of satisfaction from supporting the learning of others.

As per the grant requirement for Year 2, we obtained Institutional Review Board approval to collect and analyze data. These data would allow us to find out more about the impact of the program.

Methods

Students

Although 30 of the *SOSTA* students came from schools A and B, the other 14 students came from seven different schools in the greater southwestern area of the state. Our goal to secure ethnic diversity was achieved by having 16 (36.4%) African Americans, 19 (43.2%) White, and 9 (20.4%) non-White (i.e., 5 Asian Americans, 3 Hispanic Americans, and 1 Mexican National) students. The grade-level distribution was 36 incoming-seniors, and eight incoming-juniors. Of the 44 students at least 40 of them had previously taken Algebra I, Algebra II, and Geometry (or courses titled Integrated Mathematics I, II, and III); 33 had taken a high school trigonometry or pre-calculus; and 11 had taken calculus. Gender and ethnicity information about the students is provided in Table 2.

Table 2
Gender and Ethnic Demographics of SOSTA Students

Gender	African American *n* (%)	White *n* (%)	Non-White *n* (%)	Total *n* (%)
Female	12 (27.3)	15 (34.1)	7 (15.9)	34 (77.3)
Male	4 (9.1)	4 (9.1)	2 (4.5)	10 (22.7)
Totals	16 (36.4)	19 (43.2)	9 (20.4)	44 (100.0)

Data Sources and Instruments

Pre- and post-tests and surveys were administered on the first and last residential *SOSTA* days to assess students' general mathematical knowledge, specific pre-calculus knowledge, and mathematical dispositions. General mathematical knowledge was assessed with the 25-item Mathematics Placement Test used by MU. Additionally, a 25-item pre-calculus test was created by the course instructor scheduled to teach during the first residential week. Other *SOSTA* instructors, mathematics professors at MU and Clermont College, and members of the principal investigation team reviewed the test for content validity. This was imperative as there needed to be alignment between the curriculum coverage mandated for the state's pre-calculus TAG course and the curriculum coverage outlined in the course syllabus designed by the instructors.

A paired *t*-test analysis was performed, with *post hoc* analysis, to determine statistically significant differences between pre- and post-test performance on the Mathematics Placement Test and the pre-calculus test. Mathematical dispositions were assessed using a 60-item survey created by the principal investigators. A test of reliability of the survey yielded a Cronbach's alpha statistic, $\alpha = .681$ for the 60 items. Additional data were gathered during the Celebration Dinner in December; all students were asked to complete a brief survey, which included three items designed to measure their satisfaction with the program, reflections upon the experience with regards to future plans in mathematics or mathematics teaching, and suggested areas for program improvement. We analyzed these surveys by considering each item separately and looking for themes that emerged from the students' responses. The themes emerged "out of the data rather than being imposed on them prior to data collection and analysis" (Patton, 1990, p. 390).

Table 3
Pre- and Post-Assessments of the University Mathematics Placement Test

	M	SD	SEM	*t*
Pre-placement	8.59	3.493	.527	–6.427****
Post-placement	11.25	3.810	.524	

**** $p < .0001$.

Findings and Discussion

The *SOSTA* students represented a mixed skill-level group somewhat akin to a scenario that might take place in the traditional university setting in which students come from different schools and different mathematical backgrounds. The pre-test results indicated that of the 44 students, almost regardless of the number of high school mathematics courses taken, 35 of them would have been advised to take the lowest level mathematics course offered at MU. Eight would have been advised to take the college pre-calculus course, and only one received a score sufficient for a recommendation to take college calculus. Based upon the post-test results 26 of the 44 students would still be advised to take the lowest level mathematics class; however, 18 would have been advised to take pre-calculus (14) or calculus (4), respectively. The post-test results were better, and indicated a statistically significant difference over the pre-test results (see Table 3).

Considering the students had taken an intense two-week summer course, rather than the typical five- or six-week summer course, the results might be considered somewhat commendable for the amount of improvement during a short time. Table 3 displays the paired *t*-tests results for the comparison of the means of the pre- and post-tests of the Mathematics Placement Test. Statistically significant differences were detected as shown, $t(43) = -6.427$, $p < .0001$. Of the

Table 4
Pre- and Post-Assessments of Pre-Calculus Concepts

	M	SD	SEM	*t*
Pre-Calculus pre-test	6.09	3.672	.553	−12.158****
Pre-Calculus post-test	11.75	4.696	.708	

**** $p < .0001$.

11 students who had not taken high school pre-calculus, two of them had taken a calculus course. The remaining nine had a mean score slightly less than three points lower than the mean score for students who had pre-calculus alone or pre-calculus plus calculus. These results may call to question more about what is happening in the high school mathematics classroom, but gives some hope for students who are taught with a problem-solving approach to be able to fare well with their counterparts who may have had more high school coursework. Table 4 shares the paired *t*-tests results for the comparison of the means of the pre- and post-tests of the pre-calculus test. Statistically significant differences were detected as shown, $t(43) = -12.158$, $p < .0001$.

The dispositions survey was divided into two parts. The first part asked students to provide some demographic data and to rate themselves with respect to their mathematical knowledge on a 5-point scale: excellent (5), good (4), average (3), below average (2), or weak (1). Also, the students indicated the specific mathematics courses completed in high school before the start of our program. The following course options were listed: first year algebra ($n = 41$), geometry ($n = 40$), second year algebra ($n = 40$), trigonometry or pre-calculus ($n = 33$), statistics ($n = 4$), calculus ($n = 11$), or other ($n = 3$).

The second part of the survey consisted of 60 items. The students were asked to mark whether their response to the survey items was one of five choices: strongly agree (5), agree (4), neutral (3), disagree (2), or strongly disagree (1). A neutral response was to be selected if students felt they were undecided on a specific statement. The disposition statements addressed four specific focus areas: (a) students' attitudes toward specific mathematics topics, activities, and materials; (b) students' effort in mathematics; (c) students' interactions with their peers and teachers; and (d) students' perceptions of their own college readiness. In analysis of the survey in its entirety, Table 5 shows that there was a statistically significant difference in the pre- and post-surveys of the students' mathematical dispositions as measured by the 60-item survey, $t(43) = 10.5265$, $p < .0001$.

Table 5
Pre- and Post-Assessments of Mathematical Dispositions of SOSTA Students

	M	*SD*	*SEM*	*t*
Pre-disposition	3.836	.290	.044	10.5265****
Post-Disposition	3.431	.206	.031	

**** $p < .0001$.

It appears that the *SOSTA* students indicated improvement in their ability to do recursions and improvement in their knowledge of what the college dorm experience would be like. Survey items for which the mean student responses tended to change from higher agreement to less agreement or disagreement focused on understanding of what goes on in a mathematics class and enjoying challenging math problems. Perhaps the *SOSTA* experience enlightened them to see that there was much more to studying mathematics in a classroom than their past experiences had led them to believe. The changes in students' mean responses that were more subtle with regards to change from higher agreement to less agreement focused on: a desire to get a better understanding of mathematics; belief that hard work can increase one's ability to do math; learning best when a teacher lectures; desire to become a mathematics or science teacher; and belief that the use of graphing calculators makes mathematics problems more difficult. We wonder if the *SOSTA* experiences provided such significant challenges that the students needed us to also massage their self-images to assure them that this new level of challenge was appropriate. Perhaps we needed to assure them that as they first learned to crawl, before they could walk or run, this summer experience was merely getting them ready to become more mature in their study of mathematics.

There may have been other affective issues affecting the results of our students' work such as reflections upon one's personal image as a learner of mathematics and comparisons of one's self to others. We deliberately brought together students with various levels of previous mathematics experience and reminded

them that the college classroom might include a similar background distribution. However, we encouraged students to take heart from this summer experience in acknowledging that the problem-solving approach to pedagogy allows students to contribute in various ways. When some students met a moment of intellectual challenge, they often resorted to reminding the instructors that they had not had a pre-calculus course yet. When we attempted to convince them to stop and reflect they were often comforted by realizing that they were doing quite well. Anecdotally, when this happened they typically returned to the challenge.

End-of-Program Survey

On the evening of the Celebration Dinner students were asked to complete a three-item survey:

1. When thinking about the time you spent in *SOSTA*, please describe something that impacted you the most about the program.
2. In order to continue to improve the *SOSTA*, what is a suggestion that you think we should change or do differently next summer?
3. If you have made a college choice, where do you plan to go? If you have not yet decided, what is your current top choice?

Based on analysis of student responses (n = 33) to question 1, the biggest impact was the campus or college experience; 18 students wrote about the experience explicitly or implicitly with statements such as: it was "my first experience away from home"; I "learned how to live with other people"; I was "on my own"; I learned "time management"; or "living in dorms." The second biggest impact was similar to the first; 11 students described meeting people and making friends. One student wrote, "I got to meet a group of diverse people . . . " Another student indicated being shy, ". . . but this program helped me come out of that."

Finally, 8 students wrote about the impact of teachers and 8 wrote about learning mathematics. As for the impact of teachers, one student wrote, ". . . no one didn't [sic] give up on me" and another student noted, "The welcoming feeling among the teachers made me feel comfortable with consulting in [sic] them and asking them questions." Answering question 1, one student wrote about the mathematics and the entire program:

> The whole experience made a huge impact on my life. It took me away from home for the first time and allowed me to meet new people. The math I learned also really helped me out in my high school math class. I came into this program only expecting to learn math but I was wrong. It taught me so much more. I am very grateful for the experience.

Only one student left question #1 blank.

For the second question, students had a wide range of suggestions for change. These included more freedom (n = 7), activities with science connections (n = 1), and fewer Saturday Sessions (n = 1). Five students complained about the projects; they wanted them to be "more relevant," "fewer" and they wanted more time and help on the projects. Interestingly, one student suggested we meet two consecutive weeks (similar to Year 1). Two students had similar comments for question 2: "I don't know what you guys could improve on" and "I wouldn't change a thing."

Conclusion

As we analyzed the data from pre- and post-tests of general mathematical knowledge and pre-calculus-specific knowledge, we were not surprised to find statistically significant improvements in both. Our close work with the students during small-group learning sessions and evening study sessions gave us opportunities to witness improvement in their use of the mathematical processes (e.g., problem-solving, reasoning and proof, mathematical communication, mathematical connections, and multiple representations). These skills also translated into more active involvement in the large-group sessions. As we reflected upon our progress toward the goals for the *SOSTA* program, we felt the evidence supported success on many fronts. With that said, perhaps the three-item survey at the end of the program supplied us with some of the most useful information. The *SOSTA* students wrote about the positive impact of the college experience, meeting people and making friends, the influence of the teachers, and their experience learning mathematics.

The comments of the students substantiated our belief that immersion into the college campus culture at two environmentally different universities helped to expose them to different campus climates and supported their realization that college is more than just a place, but also a holistic experience. While building a greater since of belonging, both culturally and academically, we believe that the students also came to recognize the study of mathematics as something more multi-faceted than they had previously realized.

Relatively new facets included responsibility for reading the mathematical text and locating supportive outside resources; solving problems in groups as collaborative partners rather than the supposed "more knowledgeable" person (the teacher) dispensing knowledge to others; and extending beyond symbolic manipulation to include written narratives and confirmation of mathematical concepts in the real-world.

Efforts to develop a sense of cultural and academic belonging also gave yield to implications associated with the work of Bedsworth, Colby, and Doctor (2006). Simply, academic preparation, linking expectations to the need for a college degree, perceptions, and peer influence all play important roles in the outcomes of college access. In other words, crafting an atmosphere where students see themselves as college students and college graduates is not achieved by a single ideal, but by a culmination of factors within an environment. We know that the *SOSTA* was not a single ideal but, a multi-faceted experience that addressed the OBR's request for Ohio universities to design pre-college experiences for high school students. Data supported the notion of improvement in mathematics learning and increased familiarity and readiness for college admission. As teacher educators, we are hopeful that the *SOSTA* also motivated students to pursue careers as future mathematics or science teachers.

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Using Prediction to Promote Mathematical Understanding and Reasoning

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Research has shown that prediction has the potential to promote the teaching and learning of mathematics because it can be used to enhance students' thinking and reasoning at all grade levels in various topics. This article addresses the effectiveness of using prediction on students' understanding and reasoning of mathematical concepts in a middle school algebra context. In the treatment classroom, prediction questions were utilized at the launch of each algebra lesson, and in the control classroom such questions were not used. Both classrooms were taught by the same teacher and used the same curriculum. After completing each of the linear and exponential units, the two classrooms were compared in terms of their mathematical understanding and reasoning through unit assessments. Overall, the treatment classroom outperformed the control classroom on the unit assessments. This result supports that prediction is a valid construct with respect to enhanced conceptual understanding and mathematical reasoning.

A recent study of K-8 state mathematics standards documents revealed that each state had at least one grade-level expectation pertaining to prediction (Kim & Kasmer, 2006). Moreover, requiring students to make predictions was the most frequently occurring grade-level expectation among all those pertaining to reasoning. Researchers have suggested the effectiveness of using prediction in disciplines such as science and reading education (e.g., Garfield & Gal, 1999; Gunstone & White, 1981; Palinscar & Brown, 1984). Prediction can be used as an effective tool to promote the teaching and learning of mathematics because it can promote thinking and reasoning at all grade levels in various topics. However, little is known about using prediction in the teaching and learning of mathematics beyond the role of prediction in some specific topics (e.g., Battista, 1999; Buendía & Cordero, 2005). In this article, we address whether the use of prediction questions influences students' understanding of and reasoning about mathematical concepts in a comparative setting.

What Is Prediction?

According to Kim and Kasmer (2007b), prediction can occur at the initial stage of a mathematical exploration, and can simply be a premature guess, without being based on any plausible reasoning; conversely, it can also be a form of a sophisticated reasoning process connecting relevant topics. Prediction can also take place based on an established generalization of patterns observed, in turn linking together previously established mathematical concepts. For example, students may be asked before exploring a problem to predict what effect increasing walking rates will have on the table, the graph, and the equation as they examine the relationship between distance and time. Such questions have the potential to elicit prior knowledge and to provide opportunities to connect concepts from previous explorations. Because students view prediction questions as not having a predetermined correct response, such questions can also afford students an opportunity to engage in classroom discourse without the threat of being incorrect.

Research on Prediction

Research in various disciplines has substantiated the significance of using prediction to assist students' learning. For example, in reading education, Palinscar and Brown (1984), and Block, Rodgers, and Johnson (2004) found that the thinking processes involved in predicting helps students make meaning out of unfamiliar reading passages. To do this successfully, students must activate the relevant background knowledge they possess on the topic. Once students have made a prediction, they have a purpose, that of confirming or disproving their prediction. Furthermore, the opportunity has been created for students to link the new knowledge with the knowledge they already possess. By making predictions, students are using the following processes:

accessing prior knowledge, adding to their knowledge base, linking thinking processes, and making connections (Block et al.).

Prediction has also been found to be a valid construct in the area of science education. The American Association for Advancement of Science (AAAS) in *Benchmarks for Science Literacy* specifically addresses the significance of prediction in the teaching of science in grades K-12 (AAAS, 1993). The notion of predicting in science education as a fundamental component of scientific inquiry and process skill attainment is recognized as a "habit of mind" (Good, 1989; National Commission on Excellence in Education, 1983). For example, Gunstone and White (1981) found success with the model they developed, the Predict-Observe-Explain (POE), to teach science to secondary school students. The POE model is used to assess students' understanding by requiring students to perform three tasks. Initially, students must predict the outcome of an event and justify their prediction; students then describe what they observed, and finally they reconcile any conflict between their initial prediction and the observation. Lavoie (1999) studied the effects of supplementing lessons with a prediction/discussion phase into the POE model. Lavoie concluded that the inclusion of hypothetico–predictive reasoning "produced significant gains relative to the use of process skills, logical-thinking skills, science concepts, and scientific attitudes" (p. 1127).

There has also been some documented research in specific areas of mathematics education. In a study of students' thinking in three-dimensional geometry, Battista (1999) found that a discrepancy between predictions and actual answers made students reflect on their strategies and helped build useful mental models. Buendía and Cordero (2005) consider prediction as a social practice, which helps support the construction of meaning. They observed that while learning periodic functions, students were able to develop meaning as a result of making predictions. Based on this work, Buendía and Cordero suggest that knowledge development is a sequential process, which relies on student predictions and explanations. Cordero (1991) also found comparable results in the teaching of calculus concepts. While such studies showed the potential of using prediction in the teaching and learning of mathematics, further research is required to generalize the effectiveness of using prediction, especially comparative studies using quantitative analyses.

Potential Role of Prediction

After analyzing videotaped classroom episodes and synthesizing related literature, Kim and Kasmer (2007a) observed that prediction could play a versatile role in the teaching and learning of mathematics. While prediction helps develop and maintain students' motivation and engagement regardless of their varying mathematical abilities, prediction brings forth at least five critical benefits to instruction.

First, prediction can help students engage in sense-making. Prediction can be used to clarify what students already know, and to focus on related concepts. According to Buendía and Cordero (2005), making a prediction involves the recognition of mathematical ideas. Understanding mathematics means making sense of mathematical relationships. Boaler and Humphreys (2005) argue that learning mathematics means developing thinking habits such as looking for patterns, conjecturing, justifying, analyzing, and wondering. We believe that predicting can be considered a component of those thinking habits. Making a prediction affords students an opportunity to think about and organize previous concepts and possible connections between those concepts. Buendía and Cordero also argue that questions requiring prediction help make meaning and reorganize their mathematical thinking.

Second, prediction appears to help build connections between old and new concepts. Making predictions may allow students to make connections between previous concepts and a new problem, and these predictions can potentially be understood as connectors to the new concepts embedded in the problem. Comparing the work at hand with the predictions stated at the outset of the lesson may give students an opportunity to expand and evaluate their thinking about related concepts, which is the kind of practices that have been identified as critical to learning (Ausubel, 1968; Bransford, 1999; Hiebert & Carpenter, 1992; Lesh, 1976).

Third, prediction appears to help students visualize how they would solve a problem and what the results potentially could be. Making a prediction may provoke the visualization of a problem situation and related concepts. Often a student may produce a valid visualization of what will happen to a problem under given conditions. Visualization also makes a problem more concrete and approachable. Dunham and Osborne (1991) suggest that students learn "how to see" in order to promote conceptual understanding. While some suggest visualization may not promote

the meaning of a problem situation (Cuoco, Goldenberg, & Mark, 1996), others have found visualization to be an important tool in constructing mathematical meaning (Bishop, 1988; Brown & Wheatley, 1990; Clements, 1982; Presmeg, 2006; Skemp, 1987; Suwarsono, 1982).

Fourth, discussion regarding prediction appears to encourage alternative perspectives when looking at a problem. When students offer their predictions with supported reasoning, various perspectives may come to the forefront of the discussion. One student's prediction may help another student see the mathematics from a different perspective. Comparing different predictions and perspectives may also guide students when solving the problem.

Fifth, prediction appears to be a useful tool to assess students' thinking on relevant topics. Prediction can potentially be used as an informal assessment tool before beginning a problem. When students pose their predictions, teachers have an opportunity to garner information about what they have understood from previous explorations and what connections they have been able to make concerning the current problem. In addition, through prediction, teachers can potentially assess students' misunderstandings and misconceptions. In this case, with predictions in mind, teachers are able to adjust their plan for the lesson to focus further on the mathematics of the lesson. Prediction also allows students to assess their own thinking as they prepare to attack a new problem.

In this article, we further examine the effects of using prediction on students' conceptual understanding and reasoning in a middle school algebra setting. In particular, we address the following research question:

> To what extent, if any, are there differences in students' (a) conceptual understanding and (b) mathematical reasoning between a classroom in which prediction is deliberately integrated and a classroom where prediction is absent during lessons focusing on linear and exponential relationships?

Conceptual Understanding and Reasoning Frameworks

It is important to recognize that learning, conceptual understanding, and mathematical reasoning are not mutually exclusive entities and to acknowledge their close interrelationship. However, for the purpose of this study and analysis of data, two distinct frameworks were developed. The conceptual understanding analytical framework [CUF] was developed by synthesizing ideas presented in the current research related to conceptual understanding (e.g., Hiebert & Carpenter, 1992; National Council of Teachers of Mathematics [NCTM], 2000) and the mathematics curriculum that the participant classroom used (Lappan, Fey, Fitzgerald, Friel, & Phillips, 1998). Conceptual understanding is based on the premise that as the number of connections among ideas and concepts increases, so too does the understanding (Hiebert & Carpenter). Cognitive psychologists have agreed that conceptual understanding involves producing internal representations that are organized as networks of linkages (Hiebert & Carpenter; Royer, Cisero, & Carlo, 1993). The seven conceptual-understanding indicators of the CUF (see Figure 1) are threaded throughout the curriculum and align with the documents by the NCTM's *Principles and Standards for School Mathematics* (Standards). These indicators assisted with data analysis in the search for empirical evidence of the existence of discernable differences between treatment and control classes relative to conceptual understanding.

Conceptual understanding indicators
CU 1. Represent patterns in tables, graphs, words, and equations
CU 2. Understand and recognize patterns as linear, exponential, or something else
CU 3. Understand the meaning of a representation (an equation, a table, or a graph) as a whole and parts of it
CU 4. Understand and use the relationship among a table, an equation, and a graph (e.g., a constant in the equation is the y-intercept of a graph and the (0,b) in the table)
CU 5. Use equations, graphs, and tables to solve problems and relate the answers to problem situations
CU 6. Find a pattern (linear, exponential, or something else) in a table/graph and use the pattern to predict for a particular incident
CU 7. Identify and compare characteristics of tables and graphs of various algebraic relationships.

Figure 1. Conceptual understanding analytical framework (CUF).

The reasoning analytical framework (RF) for this study was developed as a synthesis of constructs set forth in the Standards (NCTM, 2000), *TIMMS Assessment Frameworks and Specifications* (Mullis et al., 2001), and the mathematics curriculum (Lappan et al., 1998). The RF consists of five reasoning indicators to be used as a guide to illuminate student-reasoning processes and analyze the data (see Figure 2). While the reasoning analytical framework can be used across all grades and mathematical content, the conceptual

Reasoning indicators

R1. *Formulate, evaluate, and support generalizations.*
Formulating a generalization is defined as making a statement about something true for any case.

R2. *Construct, evaluate, and support/dispute mathematical arguments.*
Constructing an argument is defined as making an informal or formal statement about a specific or general case; one form of this is making a conjecture that may lead to a generalization in the end.

R3. *Analyze/evaluate a problem situation.*
Analyzing and evaluating a problem situation is defined as making information from the problem useful for solution.

R4. *Use inductive/deductive reasoning to establish/support mathematical relationships.*
Using inductive reasoning is defined as searching for mathematical relationships through study of patterns while using deductive reasoning is defined as utilizing an established mathematical relationship to support a pattern found in a specific case.

R5. *Draw and support conclusions in varied topics.*
This indicator is about making a statement that summarizes the findings that is not necessarily a generalization or an argument.

Figure 2. Reasoning analytical framework (RF).

understanding analytical framework specifically targets middle school algebra.

Methodology

This longitudinal, quasi-experimental, mixed-methods research was designed to answer the research question. One seventh-grade classroom received the treatment of prediction questions infused into the launches of the lessons, while a similar seventh-grade classroom was taught by the same teacher using the same curriculum without any additional prediction questions. This allowed the comparison of student-learning outcomes from both classrooms in the areas of linear and exponential algebraic functions. Evidence of learning outcomes (i.e., conceptual understanding and mathematical reasoning) was examined through an analysis of data from assessments given at the end of each unit. In addition, in order to look for the classroom nature, the two classrooms were videotaped five and nine times, respectively throughout the study.

Participant Teacher

The middle school mathematics teacher selected for the purpose of this study was considered an optimal participant due to her familiarity with and experience using an inquiry-based curriculum more than 10 years, years of teaching practice, and willingness to be an integral component of the research. Furthermore, the teacher had taught middle school mathematics in this district for 11 years, had incorporated new approaches to teaching and promoting classroom discourse over time, and was interested in pursuing change in her teaching practices. She was also a member of the district's curriculum review committee that investigated curriculum alignment and textbook selection. In order to minimize her bias, she agreed that she would maintain identical routines in both classes other than implementing the prediction questions in the treatment class. In addition, the two classrooms were periodically observed to ensure the classroom instruction was consistent between the two classes.

Participant Students

Students from two of the teacher's classes were selected for this study: one class for treatment where prediction questions were purposely posed, and the other class as a control group where there was no exposure to purposely-posed prediction questions. All middle school students in this school are randomly assigned to each of their core class periods each year. In addition, selection of courses in this school does not affect classroom composition as the master schedule dictates the class periods during which core academic courses were offered and all students must take them at those times. As a result, the classrooms were considered homogeneous. Indeed, results from independent-sample *t-test*s produced no significant differences between the treatment and control groups relative to the mathematics scores ($t_{38} = .77, p < .448$) and reading scores ($t_{38} = -0.07, p < .941$) on the state test. A National Science Foundation funded middle school mathematics curriculum has been the district's adopted 6–8 grade-level mathematics curriculum for over 10 years and the two classrooms used the same algebra units.

Implementation of the Treatment: Prediction Questions

The classroom teacher posed researcher-provided prediction questions exclusively to the treatment classroom during the launch of each lesson in the linear and exponential units. We developed these prediction questions by modifying questions suggested by the curriculum or creating questions related to the mathematical concepts of the lesson.

When the teacher presented the prediction questions in conjunction with the launch of the investigation, students recorded in writing their individual responses to each prediction question posed. They were also asked to provide the reasoning behind their prediction. The teacher elicited student responses, without

Can you predict what effect increasing walking rates (e.g., 2 m/sec versus 1 m/sec) will have on the table, the graph, and the equation?
Can you predict what the three pledge plans' graphs would look like (e.g., $1.00 per mile, $2.00 per mile, $0.50 per mile w/$5.00 donation)? How do you know?
Do you predict the two companies ($5 per pound vs. $2 per pound with a minimum charge of $5) will ever charge the same amount?
Do you predict the two graphs that the two situations will produce will intersect?
Do you predict this situation will be linear or exponential? How do you know? What did you think about to help you make this prediction?
Do you predict the increase in coin value (e.g., 6% increase each year) would be linear, exponential, or something else? Explain why.

Figure 3. Sample prediction questions.

commenting on the accuracy of the prediction or appropriateness of the reasoning provided in support of it. Students were also encouraged to discuss each other's predictions and rationales. The prediction questions and student responses were revisited during the summary segment of the lesson. Examples of prediction questions are shown in Figure 3.

Unit Assessments

A unit assessment was administered to the treatment and control class at the conclusion of each unit of study. Among the assessment items provided in the curriculum, we selected or revised several assessment questions for their potential to assess students' conceptual understanding and mathematical reasoning. Each potential unit assessment question was examined to determine which distinctive features or aspect(s) of the conceptual understanding and mathematical reasoning frameworks were addressed through the particular question. One of the curriculum developers determined the assessment items corresponded and depicted the elements of CUF and RF for this study. The linear assessment was comprised of 12 items; the exponential assessment was comprised of 13 items.

Unit Assessment Analysis

Student identification was recorded on the reverse side of student written assessments and mixed to avoid coding bias. We developed scoring criteria for the unit assessment by synthesizing recommendations from the curriculum, the work of McTighe and Wiggins (1998) and the Quantitative Understanding: Amplifying Student Achievement and Reasoning (QUASAR) project (Silver & Stein, 1996). In particular, McTighe and Wiggins suggest a multifaceted perspective, such as explanation, interpretation, and application, when considering student understanding. Elements of the QUASAR general rubric were also applied as a guide to create the scoring rubric used for the unit assessments. Specifically components of the mathematical knowledge and communication indicators were adapted for data analysis purposes in this study. Anchor responses were based on acceptable responses suggested by the curriculum. Both the correctness and the supportive reasoning of the response were considered when scoring student responses. One point was awarded for a correct answer (0 or 1) and two possible points for sound reasoning of the response explanation (0, 1, or 2), depending on the sophistication of the response.

Initially, student responses were read numerous times to gain a sense of possible disparities among the student responses, and categories of student responses began to emerge. Categories were developed to help delineate the levels of sophistication found in student responses.

In order to ensure reliability of scoring, we individually scored assessments, and then compared results. Discrepancies in scoring were resolved by reconciling any differences through discussing the opposing perspectives and comparing the results to previously agreed upon scoring of items. Once coding was completed, similar codes were grouped together and revisited to confirm coding distinctions were applied uniformly and accurately. An outside reader randomly selected and coded five assessments from each group (treatment and control) and each unit of study to further ascertain reliability and consistency in coding. It was confirmed, in fact, that there was consistency in coding.

Following the completion of scoring the unit assessments, independent-sample *t*-tests were performed to determine whether the results indicated significant differences between the overall mean scores of the treatment (μ_1) and control (μ_2) classes. For the purpose of hypothesis testing relative to the unit assessments, the following hypothesis were posed utilizing a one-sided test with H_a: $(\mu_1 - \mu_2) > 0$, and a significance level of $\alpha = .05$. Cronbach's alpha, or the reliability coefficient, was also used to measure the internal consistency of all the unit assessment items in order to determine whether items in each unit could be combined with items in the other unit. This helped to see whether there was a difference between the two classrooms in terms of overall unit assessment results.

While the first step of the analysis was to consider the comparison of total mean scores between the treatment and control classes, it was also deemed important to investigate the individual components of the CUF and the RF. As such, the assessment items were grouped, compared and tested for each CUF and RF indicator between the treatment and the control

classes. For example, students' scores of all the items addressing CU1 were used to determine the mean of CU1. This was done to further identify specific components of conceptual understanding and mathematical reasoning where the two classes might exemplify differences.

Results

This section presents the statistical analysis of the unit assessments, and the analysis of the conceptual understanding and mathematical reasoning indicators. Also, examples of students' responses highlighting their conceptual understanding and mathematical reasoning are described.

One-tailed independent sample *t*-test results of the linear assessment, exponential assessment, and the combined scores of the linear and exponential units are presented in Table 1. Data from the linear relationships assessment produced a mean score of 16.98 in the treatment class and 15.13 in the control class. The one-tailed independent-sample *t-test* results generated a *p*-value of .079, and consequently these results are considered to be marginally significant. Conversely, the analysis of the exponential relationships data indicated statistically significant results with a *p*-value of .008. Also, Cohen's *d* effect size generated a value of 0.830, which suggests a high effect of the treatment in this unit.

Levene's Test for Equality of Variance (linear .120, exponential .297) found that the evidence is not strong to suggest that the variances of the two distributions differ significantly, that is, the assumption that the treatment and control classes demonstrate approximately equal variance on the dependent variable. In addition, the result of Cronbach's alpha (.612), a measure of reliability that is based on inter-item correlation and internal consistency, suggests that the results from items from the linear and exponential unit assessments can in fact be combined for further analysis. When combining the student scores from the linear and exponential units the results of the independent sample *t*-tests render that these are in fact statistically significant ($t_{36} = 2.26$, $p < .015$), with a high effect size of .700. Therefore, the statistical results indicated that overall the treatment class outperformed the control class.

Conceptual Understanding

The conceptual understanding indicators within each unit assessment and the two combined were investigated through one-tailed independent-samples *t*-tests (see Tables 2–4). An examination of the conceptual understanding indictors revealed that CU1 in the linear relationships unit and CU1, CU2, CU3, CU6, and CU7 in the exponential unit were statistically significant; *p*-values .042, .005, .005, .030, .050, and .048, respectively. Corresponding effect sizes .561, .878, .0762, .634, .542, and .561 suggests medium to high effect. From the combined scores of the linear and exponential, indicators CU1, CU2, and CU3 were statistically significant (*p*-values .004, .023 and .029, and effect sizes 0.906, 0.674, and 0.640, respectively).

Student Responses Regarding Conceptual Understanding Indicators. The following example that encompasses CU1, CU2, CU3, CU4, and CU7 indicators is provided to demonstrate discernable

Table 1
Independent-Sample t-test for Treatment versus Control for Equality of Means

Unit		*N*	Mean	*SD*	*t*-tests	*p*-Value	Effect–Size Cohen's *d*
Linear	Treatment	20	16.98	3.39	$t_{38} = 1.44$	.079	
	Control	20	15.13	4.64			
Exponential	Treatment	19	23.74	2.33	$t_{36} = 2.55$	.008*	.830
	Control	19	20.55	4.38			
Combined	Treatment	19	40.41	4.86	$t_{36} = 2.26$	.015*	.700
	Control	19	36.16	7.08			

Note. Linear total possible 23 points. Exponential total possible 34 points.
* Statistically significant at $\alpha = .05$
The combined results are based on the scores of those who participated in both assessments.

Table 2
Comparison of Conceptual Understanding Linear Unit

	Class	Linear Unit				
		Mean	*SD*	*t*-tests	*p*-Value	Effect–Size Cohen's *d*
CU1	Treatment	6.02	1.36	$t_{38} = 1.78$	.042*	
	Control	5.05	2.03			
CU2	Treatment	1.32	1.00	$t_{38} = -.72$	.472	
	Control	1.35	1.18			
CU3	Treatment	8.83	2.56	$t_{38} = 1.48$	.073	
	Control	7.57	2.76			
CU4	Treatment	5.58	1.61	$t_{38} = .53$	.298	
	Control	5.28	1.92			
CU5	Treatment	5.80	1.67	$t_{38} = 1.66$	.053	.530
	Control	4.75	2.28			
CU6	Treatment	3.30	1.30	$t_{38} = 1.13$	.134	
	Control	2.80	1.50			
CU7	Treatment	1.33	1.00	$t_{38} = -.72$	.472	
	Control	1.35	1.18			

* Statistically significant at $\alpha = .05$.

differences between responses from the treatment class compared to those of the control class. As indicated from the *t*-test results, students in the treatment class outperformed the control class in most of these indicators. In order to illuminate these indicators, one unit assessment item is highlighted below.

Students were presented with the following question from the exponential relationships assessment (see Figure 4).

In this item, students are expected to make use of the information presented in the table and determine the decay factor in order to generate an equation that accurately models the information presented in the table. The decay factor can be arrived at by examining the pattern in the increasing whale population. Students are also expected to represent the algebraic pattern in an equation. When students respond to this item, they are required to recognize the pattern in the table as an exponential decay (CU2) and identify its characteristics (CU7), to represent the pattern in an equation (CU1), to understand the meaning of the equation (CU3), and to make a relationship between the table and the equation (CU4). A student from the control class responded:

> I know C wasn't because it was linear and the table is exponential. I knew it wasn't D because that would increase and the table is falling so far. A and B I put 2 in for y in the equation and B matched.

While this student selected the correct response (B), the reasoning revealed little understanding of key mathematical ideas such as the decay factor. The student was uncertain whether 0.1 or 0.9 was the decay factor for this situation; consequently he entered both equations in the graphing calculator to determine the correct response by comparing the table data presented in the test, and those generated on the graphing calculator. This student incorrectly considered selection (C) as a linear relationship, even though all the choices are exponential. It appeared the student was unsure of the correct equation that models this situation and resorted to guess and check to select the

Table 3
Comparison of Conceptual Understanding Exponential Unit

	Class	Linear Unit				
		Mean	*SD*	*t*-tests	*p*-Value	Effect–Size Cohen's *d*
CU1	Treatment	10.47	2.03	$t_{36} = 2.70$	.005*	.878
	Control	8.63	2.16			
CU2	Treatment	10.26	2.42	$t_{36} = 2.70$	.005*	.762
	Control	8.42	2.41			
CU3	Treatment	15.16	2.38	$t_{36} = 1.94$	.030*	.634
	Control	13.57	2.63			
CU4	Treatment	7.94	1.58	$t_{36} = .70$	.245	
	Control	7.57	1.67			
CU5	Treatment	4.94	.77	$t_{36} = 1.38$	.087	
	Control	4.52	1.07			
CU6	Treatment	2.84	.37	$t_{36} = 1.61$	.050*	.542
	Control	2.57	.60			
CU7	Treatment	6.90	1.48	$t_{36} = 1.70$	.048*	.561
	Control	6.10	1.37			

* Statistically significant at $\alpha = .05$.

appropriate response. On the other hand, a student from the treatment class responded:

> [B] because the starting point is 5,000 so the 5,000 outside the parenthesis is right. When you divide 4,500 ÷ 5,000 you find the decay factor is .9. So you see .9 is decaying exponentially to the x. So as indicated $.9^x$ in the parenthesis makes sense so it's all correct.

The student recognized the initial value of 5,000 and was able to associate this to (0, 5000) on the table. In addition, the student calculated the decay factor, albeit further verification of this was not pursued. The students' response communicated understanding of the various components of the equation as they were reflected in the table. Another student from the treatment class explained:

> The starting point is 5000, and the decay factor is 0.9. So first I did 4500 ÷ 5000 to get 0.9, the decay factor. So with the starting point of 5000, and a decay factor of 0.9, the equation would have to be $w = 5000\ (0.9^x)$.

As described above, this student was able to recognize and attach meaning to the components of the equation ("starting point is 5000" and . . . 4500 ÷ 5000 = .9 being the decay factor), and represent patterns in an equation. This level of response from the treatment class was reported for 42% of the student responses while 31% of the student responses from the control class were considered comparable relative to this particular assessment item. Responses less conceptual, not attaching meaning to the components of the equation, or relying on guess and check were 16% in the control class and 10% in the treatment class to this item.

Mathematical Reasoning

Similar to the previous section, further analysis using *t-tests* were performed on the mathematical reasoning indicators from each unit and the two assessments combined (see Tables 5–7). The mathematical reasoning indicators R3 and R5 proved to be statistically significant in the linear unit, and R1, R2, R4, and R5 in the exponential unit; *p*-values .042, .030, .029, .050, .010, and .005, respectively. Corresponding effect sizes .590, .651, .636, .522, .784, and

Table 4
Comparison of Conceptual Understanding Combined Units

	Class	Linear Unit				
		Mean	*SD*	*t*-tests	*p*-Value	Effect–Size Cohen's *d*
CU1	Treatment	14.44	2.64	$t_{36} = 2.79$	.004*	.906
	Control	12.07	2.59			
CU2	Treatment	11.55	2.44	$t_{36} = 2.08$	.023*	.674
	Control	9.84	2.63			
CU3	Treatment	23.92	3.52	$t_{36} = 1.97$	.029*	.640
	Control	21.44	4.20			
CU4	Treatment	13.40	2.38	$t_{36} = .45$	.329	
	Control	13.02	2.70			
CU5	Treatment	10.79	1.99	$t_{36} = 1.65$	.054	
	Control	9.47	2.86			
CU6	Treatment	6.21	1.54	$t_{36} = .79$	.092	
	Control	5.47	1.80			
CU7	Treatment	8.18	1.57	$t_{36} = 1.29$	.103	

* Statistically significant at $\alpha = .05$. The combined results are based on the scores of those who participated in both assessments.

Several species of whale have been declared endangered. When the populations of a particular whale species fall dangerously low, biologists encourage governments to agree to a ban on hunting the species. Suppose that, in the year 2000, there were only 5,000 whales of a particular species and that the population was predicted to continue to decline as shown in the table.

Year (y)	Whales (w)
0 (2000)	5,000
1	4,500
2	4,050
3	3,645
4	3,281
5	2,952
6	2,657

Which equation below models this population pattern? Explain how you determined your answer.

A. $W = 5{,}000\left(0.1^{y}\right)$ B. $W = 5{,}000\left(0.9^{y}\right)$ C. $W = 5{,}000 - 500^{y}$ D. $W = 5{,}000^{y}$

Figure 4. Exponential relationships assessment item.

.878 suggest medium to high effect. The reasoning indictors presented in the linear and exponential units combined revealed that R2, R4, and R5 were statistically significant with *p*-values .043, .040, .004, and corresponding effect sizes .575, .586, and .925, respectively.

The subsequent examples will provide further details on students' reasoning on algebraic relationships between the treatment and control classes. The question below from the exponential unit assessment illuminates R2, R4, and R5 indicators.

> Carlos said, "The difference between a table that shows exponential growth and exponential decay is if the X values go up, or down." Is Carlos correct in his thinking? Why or why not? How might

Table 5
Comparison of Mathematical Reasoning Linear Unit

	Class	Linear Unit				
		Mean	*SD*	*t*-tests	*p*-Value	Effect–Size Cohen's *d*
R1	Treatment	6.70	2.07	$t_{34} = 1.42$	.444	
	Control	6.59	2.44			
R2	Treatment	5.18	1.53	$t_{34} = .96$	.152	
	Control	4.66	1.72			
R3	Treatment	6.23	1.58	$t_{34} = 1.78$	.042*	.590
	Control	5.13	2.11			
R4	Treatment	11.15	2.94	$t_{34} = .62$	.252	
	Control	10.41	4.21			
R5	Treatment	6.55	2.11	$t_{34} = 1.95$	.030*	.651
	Control	5.13	2.25			

* Statistically significant at $\alpha = .05$.
The combined results are based on the scores of those who participated in both assessments.

Table 6
Comparison of Mathematical Reasoning Exponential Unit

	Class	Exponential Unit				
		Mean	*SD*	*t*-tests	*p*-Value	Effect–Size Cohen's *d*
R1	Treatment	17.52	2.65	$t_{36} = 1.96$	.029*	.636
	Control	15.57	3.43			
R2	Treatment	13.68	2.21	$t_{36} = 1.60$	.050*	.522
	Control	12.36	2.81			
R3	Treatment	14.10	1.66	$t_{36} = 1.14$	.131	
	Control	13.26	2.76			
R4	Treatment	19.84	2.63	$t_{36} = 2.41$	.010*	.784
	Control	17.26	3.84			
R5	Treatment	10.47	2.03	$t_{36} = 2.70$	.005*	.878
	Control	8.63	2.16			

* Statistically significant at $\alpha = .05$.

Carlos explain the differences in the graphs of exponential growth and decay? How might he explain the differences in the equations? Explain your thinking.

In this assessment item, students were expected to address the notion that the x values do not determine whether a table suggests an exponential relationship. Moreover, students should be able to articulate the

Table 7
Comparison of Mathematical Reasoning Combined Units

	Class	Combined		†Liner and Exponential Units		
		Mean	*SD*	*t*-tests	*p*-Value	Effect–Size Cohen's *d*
R1	Treatment	24.10	3.68	$t_{36} = 1.39$	.087	
	Control	22.18	4.78			
R2	Treatment	18.86	2.59	$t_{36} = 1.77$	.043*	.575
	Control	17.10	3.47			
R3	Treatment	20.34	2.05	$t_{36} = 1.60$	.059	
	Control	18.68	4.01			
R4	Treatment	30.84	4.07	$t_{36} = 1.80$	.040*	.586
	Control	27.76	6.22			
R5	Treatment	17.05	2.83	$t_{36} = 2.85$	.004*	.925
	Control	14.26	3.19			

* Statistically significant at $\alpha = .05$.
† The combined results are based on the scores of those who participated in both assessments.

differences in the appearance of the graphs of exponential growth and decay. In addition, students must speak to the idea that a growth factor must be larger than one, whereas the decay factor will be greater than zero and less than one. One student response from the treatment class is:

> Carlos is wrong because the *x* value will always go up. He should explain the difference in the graphs by saying if the graph goes up it is exponential growth and if it goes down it is exponential decay. In the equation if the base [growth factor or decay factor] is greater than 1 it is growing if it is a percent it is decaying.

Since the question assumed that the graphs were exponential, the response was considered to contain sophisticated reasoning, encompassing explicit and logical thought processes. In the selection above, the student was able to make and dispute a mathematical argument (R2). The student evaluated the statement made by Carlos, stated a claim ("Carlos is wrong because the x value will always go up") and elaborated by providing supportive and accurate rationale for his argument. He also utilized deductive reasoning (R4) in his arguments as he applied his knowledge of growth factors (greater than 1) and decay factors (greater than zero and less than 1) to this particular situation. In this example, the student was also able to draw and support a conclusion (R5). The student also precisely addressed the differences in the equations of exponential growth situations and exponential decay situations. While the nature of these responses typified 37% of the treatment class, this is contrasted to 26% of the responses from the control class. In contrast, student responses lacking clarity, accuracy, and reasonableness were found .05% in the treatment class, and 26% in the control class.

Another example of the reasoning indicators is presented in the following question in the exponential unit assessment that under scores indicators R1, R2, R4:

> Belinda has a plan for distributing prize money for a trivia contest. For the first correct response, the contestant will receive $500. For the second correct response, the contestant will receive an additional $100, for a total of $600. For the third correct response, the contestant will receive $100 more, for a total of $700. Belinda's plan continues in this pattern. After making a table and graph of the situation answer the following question: Is this

pattern linear, exponential, or something else? Explain why, and how do you know? Write a convincing argument to a classmate to support your thinking.

It was anticipated that students would be able to correctly identify that this situation is in fact a linear relationship as well as address the appearance of the graph (i.e., straight line) and the constant rate of change. In addition, students were expected to articulate why this situation was not an exponential model. Representative responses selected from the treatment class are described below.

> Linear. Firstly, it makes a straight line on the graph. Straight lines means its linear. Secondly, it goes up 100 every time, and exponential patterns don't always go up a certain number. Thirdly there's no exponents in the equation, and exponential patterns need exponents.

> It's linear because each time you add 100. You add in linear relationships you don't multiply like in exponential. Also exponential graphing are J shaped and linear is straight this graph is a straight line so it's linear.

The students demonstrated the ability to distinguish key components of linear and exponential relationships. Each student was able to appropriately identify a fundamental characteristic of a linear relationship; that is the notion of constant rate of change ("it does up 100 every time," "each time you add 100"). The students also correctly addressed aspects of exponential patterns ("exponential patterns don't always go up a certain number," "exponential patterns need exponents," "exponential graphing are J shaped".) By using and comparing characteristics of linear and exponential relationships these students were able to make a convincing argument (R2) and support their claims while evaluating and supporting generalizations about the attributes of these relationships (R1). Evidence of inductive reasoning is apparent as students examine the specific case of the contest situation and relate to the general properties of linear and exponential relationships (R4). Similar responses from students in the treatment class were observed, 74% of all responses for this particular question, whereas 32% of the responses scored from the control class were of a similar nature.

Potential Contributions to the Differences

Overall study results suggest that the students using prediction showed better mathematical understanding and reasoning than the students without using prediction. What aspects of using prediction may have contributed to this difference is an immediate question that arises. The control and treatment classrooms were observed to look for the classroom nature, five and nine times, respectively. As described previously, the teacher was using the same curriculum in the two classrooms and was asked to do her routines in her teaching except using prediction in the treatment class. When comparing the classroom environment, however, there was notable distinction between the treatment and control classes. The treatment students, as evidenced from videotaped data and teacher reflections, appeared to be more actively engaged and have richer discussions on the concepts they learned. It was noted that almost all of the students in the treatment class raised their hands in response to the teacher's questions as compared with the control class where typically only three or four students would raise their hands. Also, these students participated in more focused discussions centered on the mathematical concepts of the lesson. In contrast, at the beginning of the study, the teacher had difficulty engaging students in whole group discussion in both classrooms. Another observation noted was that when students were instructed to begin working on the explore segment of the task, students in the treatment class were motivated to begin the problem with curiosity about the correctness of their predictions.

Providing all students with purposeful time devoted to consolidating their individual thinking before responding to the prediction questions may have led to richer discussions that reflected the students' connections to related mathematical ideas previously learned. In fact, with prediction questions, the teacher tended to organize the classroom discussion in a way that encouraged students' understanding and reasoning, rather than dominating the discussion or simply giving out information. Students in the treatment class were engaged in sustained conversations that were created by a culture precipitated by the inherent risk free virtue of prediction questions. Moreover, the task of requiring students to respond in writing to the prediction prompts created another avenue for students to synthesize their thinking. This notion of student engagement, motivation and providing

students opportunities to synthesize their thinking while connecting to previous knowledge appears to contribute to the efficacy of using prediction in the mathematics classroom.

Conclusion

Research has shown that academic areas such as science and reading have benefited from the instructional practice of including prediction questions in the course of learning. Such research has indicated improved performance in reading comprehension and the understanding of complex ideas in the study of physics (Block et al., 2004; Gunstone & White, 1981; Lavoie, 1999). Providing students with opportunities to make predictions helps activate prior knowledge and connect to prior learning, and engage students in their learning process.

While there has been limited research regarding the benefits of prediction in mathematics, some positive aspects have been reported (Battista, 1999; Buendía & Cordero, 2005; Cordero, 1991). However, there is a noticeable paucity of research on the effectiveness of using prediction questions in the teaching of mathematics especially in a comparative setting. This dearth of research was the impetus of the present study.

In order to extend and build on our knowledge about the positive effects of using prediction, the study explored this instructional practice in the context of algebra using a quasi-experimental design. In particular, we attended to conceptual understanding and mathematical reasoning in this study. Facilitating students' shift from rote memorization to a conceptual understanding and ability to reason mathematically, which allows them to develop the underlying structures of mathematics, has been at the forefront of recent mathematics education reform efforts.

The results of this study show that using prediction benefits students' mathematical understanding and reasoning. Previous research has clearly demonstrated that students are able to attain conceptual understanding and mathematical reasoning if explicit connections to previous acquired mathematical ideas are attended to (Gamoran, 2001; Hiebert & Carpenter, 1992; Kilpatrick, Swafford, & Findell, 2001). Through making predictions, students had an opportunity to relate what they already knew with the mathematics of a new problem. In addition, prompting students by posing prediction questions at the launch of a lesson engaged all students in the classroom. Thus, prediction questions provided an opportunity for all students to build upon their conceptual understanding and reasoning of mathematical ideas. In fact, entry knowledge and student engagement are two fundamental factors of opportunities to learn, which the National Kilpatrick and his colleagues regard "as the single most important predicator of student achievement" (p. 334).

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PROBLEMS section

Ted Eisenberg, *Section Editor*

This section of the Journal offers readers an opportunity to exchange interesting mathematical problems and solutions. Please send them to Ted Eisenberg, Department of Mathematics, Ben-Gurion University, Beer-Sheva, Israel or fax to: 972-86-477-648. Questions concerning proposals and/or solutions can be sent e-mail to eisenbt@013.net. Solutions to previously stated problems can be seen at http://ssmj.tamu.edu.

Solutions to the problems stated in this issue should be posted before March 15, 2011

• **5140:** *Proposed by Kenneth Korbin, New York, NY*

Given equilateral triangle ABC with an interior point P such that

$$\overline{AP} = 22 + 16\sqrt{2}$$

$$\overline{BP} = 13 + 9\sqrt{2}$$

$$\overline{CP} = 23 + 16\sqrt{2}.$$

Find $\overline{AB}$.

• **5141:** *Proposed by Kenneth Korbin, New York, NY*

A quadrilateral with sides 259,765,285,925 is constructed so that its area is maximum. Find the size of the angles formed by the intersection of the diagonals.

• **5142:** *Proposed by Michael Brozinsky, Central Islip, NY*

Let CD be an arbitrary diameter of a circle with center O. Show that for each point A distinct from O, C, and D on the line containing CD there is a point B such that the line from D to any point P on the circle distinct from C and D bisects angle APB.

• **5143:** *Proposed by Valmir Krasniqi (student, University of Prishtina), Prishtina, Republic of Kosova*

$$\sum_{n=1}^{\infty} Cos^{-1}\frac{1+\sqrt{n^2+2n}\cdot\sqrt{n^2-1}}{n(n+1)} = \frac{\pi}{2}.$$
$$\left(Cos^{-1} = Arccos\right)$$

• **5144:** *Proposed by José Luis Díaz-Barrero, Barcelona, Spain*

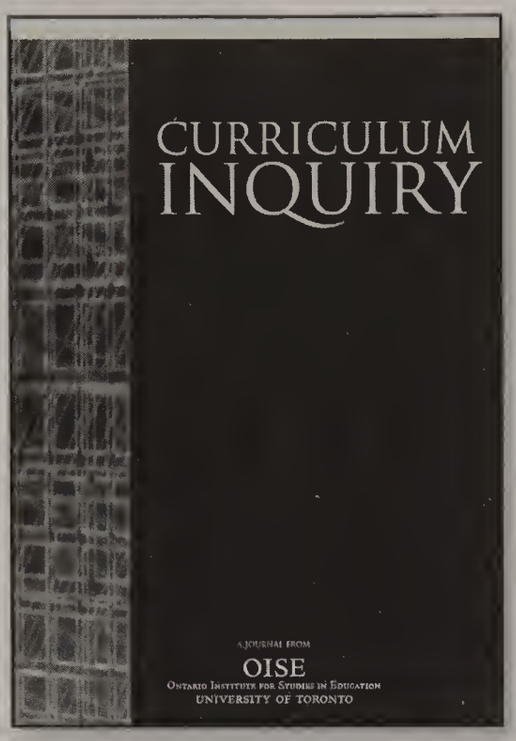
Compute

$$\lim_{n\to\infty}\prod_{k=1}^{n}\left[1+\ln\left(\frac{k+\sqrt{n^2+k^2}}{n}\right)^{1/n}\right].$$

• **5145:** *Proposed by Ovidiu Furdui, Cluj, Romania*

Let k $\geq$ 1 be a natural number. Find the sum of

$$\sum_{n=1}^{\infty}\left(\frac{1}{1-x}-1-x-x^2-\cdots-x^n\right)^k, \text{ for } |x|<1.$$



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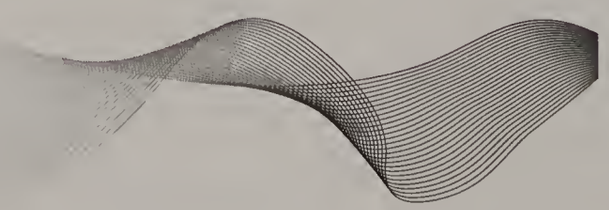

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Research manuscripts only:

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Analyses of data
Conclusions based on results
Results related to professional practice and literature
Enough information to enable replication (quantitative)

SCHOOL SCIENCE AND MATHEMATICS

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IN THIS issue

Research in the Classroom: Using Instructional Logs to Study Teachers' Adaptation to Curricular Reform

Paula R. Stickles

In this study, the characteristics of teachers that motivate their implementation of reform curriculum, and the factors that influence the teachers' success in implementing the curriculum, are investigated. In particular, teachers' internal struggles, frustrations, collegiality, and classroom successes during the implementation of the reform curriculum, are considered. From data gathered from elementary school teachers through electronic instructional logs, a classification emerges that suggests that teachers fall into three broad categories based on their characteristics. Implications and future research directions are suggested.

"Natural Philosophy" as a Foundation for Science Education in an Age of High-Stakes Accountability

Cory Buxton, Eugene F. Provenzo, Jr.

Science curriculum and instruction in K-12 settings in the United States is currently dominated by an emphasis on the science standards movement of the 1990s, and the resulting standards-based high-stakes assessment and accountability movement of the 2000s. We argue that this focus has moved the field away from important philosophical understandings of science teaching and learning that have their roots in the history of both learning theory and scientific discovery. We offer a philosophical argument, as well as a model for implementation, grounded in the 19th century notion of "natural philosophy," as well as Dewean progressivism and Piaget's notion of reconstruction through rediscovery, for the important place of the history of science in modern science education. We provide curricular examples of this model, as well as a discussion of how it might be implemented as part of teacher education. We focus our discussion on the elementary and middle school grades, because teachers at these levels tend to have more limited science content knowledge than their secondary school peers, making them more dependent upon curricular materials and thus more heavily influenced by curricular reforms.

Preservice Mathematics Teachers' Ambiguous Views of Technology

Rong-Ji Chen

While the nature of mathematics and the nature of science have received much attention, there is a lack of research on the nature of technology. This study sought to investigate preservice teachers' perceptions about the nature of technology and its role in mathematics education and society. Based on two philosophical theories of technology, the author analyzed 22 preservice teachers' philosophy statements on educational technology and in-depth interviews with 5 of them. The findings reveal that the teachers had ambiguous notions about the characteristics of technology, which were contingent on contexts of technology use, human–machine relationships, and other factors. However, in most cases, they had an instrumental view of technology and a techno-centric mindset. Although the participating teachers were encouraged to reflect on broad socio-cultural issues associated with technology, most of them did not have a linguistic and conceptual framework from which to examine thoroughly how technology might influence human consciousness. As the educational technology and teacher education communities have broadened their understanding of technology and what it takes for an organizational change, preservice teachers need adequate opportunities to explore the pedagogical, epistemological, ontological, and cultural implications of the educational use of technology.

"Mathematicians Would Say It This Way": An Investigation of Teachers' Framings of Mathematicians

Michelle Cirillo, Beth Herbel-Eisenmann

Although popular media often provides negative images of mathematicians, we contend that mathematics classroom practices can also contribute to students' images of mathematicians. In this study, we examined eight mathematics teachers' framings

of mathematicians in their classrooms. Here, we analyze classroom observations to explore some of the characteristics of the teachers' framings of mathematicians in their classrooms. The findings suggest that there may be a relationship between a teachers' mathematics background and his/her references to mathematicians. We also argue that teachers need to be reflective about how they represent mathematicians to their students, and that preservice teachers should explore their beliefs about what mathematicians actually do.

Paula R. Stickles
Millikin University

Using Instructional Logs to Study Teachers' Adaptation to Curricular Reform

In this study, the characteristics of teachers that motivate their implementation of reform curriculum, and the factors that influence the teachers' success in implementing the curriculum are investigated. In particular, teachers' internal struggles, frustrations, collegiality, and classroom successes during the implementation of the reform curriculum are considered. From data gathered from elementary school teachers through electronic instructional logs, a classification emerges that suggests that teachers fall into three broad categories based on their characteristics. Implications and future research directions are suggested.

As the mathematics classroom becomes more learner-centered, the teacher's role changes. The teacher becomes more of a facilitator rather than the disseminator of all knowledge. As the role of a teacher changes, the following questions arise: What personality traits, or teacher characteristics, motivates a teacher's implementation of the curriculum? What factors influence a teacher's success in implementing the curriculum? The search for answers to these questions to help future reform curriculum implementations is the motivation for this research.

Background

With the wave of reform sweeping mathematics education today, educators must step back and consider what is appropriate in the classroom. "Students must learn mathematics with understanding, actively building new knowledge from experience and prior knowledge" (National Council of Teachers of Mathematics [NCTM], 2000, p. 20). Standards-based programs advocate classrooms that meet content standards and pedagogical approaches. Teachers are encouraged to spend less time on transmission of information and allow more time for students to explore and create mathematics through problematic situations introduced by the teachers. McCaffrey et al. (2001) found reform curriculum-based classrooms may be more effective when designed to be consistent with standards-based reform. The NCTM *Standards* (NCTM, 1989, 1991, 1995, 2000) recommend providing an opportunity for all students to learn, and places a curriculum emphasis through its five content standards on number and operations, algebra, geometry, measurement, and data analysis and probability.

"The teacher of mathematics should orchestrate discourse by posing questions and tasks that elicit, engage, and challenge each student's thinking" (NCTM, 1991, p. 35). Teachers should embrace the idea that students learn by experiencing and doing mathematics as opposed to merely receiving information through transmission. Problem solving plays "an essential role in student's learning of mathematical content and in helping students make connections across mathematical content areas" (NCTM, 2000, p. 334). Students' perceptions and beliefs about mathematics often stem from the types of activities that occur in the mathematics classroom. The posing of a mathematical task is of great importance in the course of mathematical thinking (Brown, 1996; Silver, Mamona-Downs, Leung & Kenney, 1996). Through frequent problem solving and problem posing, students develop conceptual understanding of numbers and operations. Reform mathematics education encourages learning through investigation.

Lambdin and Preston (1995) analyzed data collected from 34 sixth-grade teachers who were implementing a pilot version of a reform curriculum, Connected Mathematics Project (CMP). As part of the study, the implementation of the curriculum including changes in classroom dynamics and the support needs of the teachers included in the study were documented. In reviewing the data collected, Lambdin and Preston identified similarities among the teachers' mathematics backgrounds, teaching methods, and

their efforts to implement the CMP curriculum. As a result of the analyses, Lambdin and Preston identified three categories of teachers that emerged from the data. Lambdin and Preston adopted Noss and Hoyles's (1993) method of describing results via caricatures.

The three caricatures are the Frustrated Methodologist, Teacher on the Grow, and Standards Bearer. The Frustrated Methodologist has a strong mathematics background and is resistant to changing the teaching methods necessary to implementing CMP. The Teacher on the Grow has a weak mathematics background and has difficulty implementing some of the CMP curriculum, but yet has embraced the teaching methods necessary to effectively implement the curriculum. The Standards Bearer has a strong mathematics and pedagogical background and has found the CMP curriculum to be an excellent match of educational philosophy, and thus, has successfully implemented the curriculum. After the first year of their study, Lambdin and Preston found that the breakdown of teachers in the study was about 20% Frustrated Methodologists, 60% Teachers on the Grow, and 20% Standards Bearers.

However, simply adopting a reform curriculum is not enough to make a difference in the classroom. It is the teachers' implementation of the curriculum that deserves our attention. Students' perceptions and beliefs about mathematics stem from the type of activities that occur in the classroom. The teachers' role in these activities is crucial. Thus, it is important to understand the teachers' struggles and frustrations they encounter when implementing a new curriculum.

Indiana Mathematics Initiative

The Indiana Mathematics Initiative (IMI) initially received funding from the National Science Foundation in 1997 to plan and implement a 5-year middle grades mathematics local systemic change project. The project included 53 middle schools involving over 500 teachers and 55 administrators in IMI districts. As an outgrowth of that project, in 2000, a mathematics–science partnership grant from the National Science Foundation, funded a partnership formed between Indiana University-Bloomington and nine urban school corporations (the Indiana Initiative Mathematics Consortium). There are a total of 126 elementary schools (57 Title I[1]), 36 middle schools and 24 high schools in the districts serving over 115,000 students. Two major foci of the project are (1) providing comprehensive professional development for leadership cadres of teachers and principals; and (2) ensuring all IMI districts derive permanent benefits from a major overhaul of the preservice preparation of elementary and high school teachers by the university.

One focus of the project is the identification of a group of elementary teachers to effectively pilot a mathematics curriculum, which aligns with the Indiana 2000 academic standards (Indiana Department of Education, 2004), as well as the National Council of Teachers of Mathematics (NCTM) *Principles and Standards* (2000), in order to improve student academic achievement. The teachers involved in the partnership pilot University of Chicago School Mathematics Project's *Everyday Mathematics*. The curriculum includes real-life problem solving and an emphasis on communication with students actively engaged in groups or pairs exploring mathematics ideas. The curriculum was identified as an exemplary curriculum by district coordinators, and it was anticipated that several districts would adopt the curriculum in the upcoming adoption year. The teachers participate in summer and academic year workshops designed to increase teachers' understanding of NCTM's *Standards* and their connection to the Indiana mathematics standards, as well as the reform vision of mathematics education. The teachers also submit weekly learning logs (via the Internet). The logs chronicle their implementation of the curriculum, and the teachers receive advice from a log reader (EM consultant) to maintain the impact of face-to-face workshops. The learning logs were an opportunity for the teachers to reflect on their lessons and the activities they implemented in their classroom. Additionally, they could pose questions and concerns to the log readers, as well as share successes and failures. As part of the process, the hope is teachers will develop into leaders in using the reform curriculum in their schools and districts. Of the initial nine school districts that had teachers who piloted *Everyday Mathematics*, eight have adopted the curriculum throughout the elementary schools. In addition, the teachers involved in the piloting project serve as lead teachers to help all teachers in the district implement the curriculum.

Methodology

There are over 10,000 learning logs submitted by 277 teachers (not all teachers are included as data is still being collected from some of them) ranging from grades 2 to 5 inclusive. After assigning numbers to each of the learning logs, a random number generator selected the initial 50 learning

logs, which were used for the identification of common themes. Learning logs were separated into stacks of logs containing similar comments, which resulted in the beginning of the identification of emerging themes. After reviewing the 50 learning logs, recurring themes were beginning to emerge, but were not solidified. As a result, two more random samples of 50 were generated for a total of 150 logs. With the additional 100 learning logs, the recurring themes became clear. The review of the additional logs led to the identification of recurring themes such as pedagogical concerns, (lack of) content knowledge, and the difficulties and successes in the implementation of the curriculum. Through the search for and identification of recurring themes among the teachers, common characteristics of the teachers that are related to the themes became apparent.

The characteristics that emerged separate the teachers into three broad categories. The findings have been adapted for description as caricatures in the same light as Noss and Hoyles (1993), and as implemented by Lambdin and Preston (1995). The caricatures represent classes of teachers in which the emphasis is on the striking characteristics. However, they are written as if describing an individual teacher. (All quotes in the descriptions of the caricatures come from the learning logs. However, some of the quotes were edited to preserve the anonymity of the teachers.) Also, not all teachers who may be classified as one of the caricatures will necessarily take on all the characteristics of that caricature.

After the development of the caricatures, numbers were assigned to each of the 277 teachers participating in the project. A random number generator selected 50 teachers for use in validating the results. Each of the 50 teachers' logs for the entire year was reviewed to identify which caricature (if any) the teacher best fit. The logs that had been used in identifying common themes represented only a week's worth of reflection from any given teacher. However, the learning logs for the entire year were used for the 50 teachers selected for use in validating the results. On average, each of the 50 teachers had submitted 38 logs over the course of a year.

Results

Three distinct caricatures emerge from the data. Each caricature represents a class of teachers, and the emphasis in each caricature is on the distinguishing characteristics of the teachers. Although the caricatures are based on a class of teachers, each caricature is written as if discussing a single teacher.

The first caricature is the Conflicted Traditionalist, and it represents the teachers who have attempted to immerse themselves in the *Everyday Mathematics* curriculum. However, they are frustrated by the amount of time it takes to prepare the lessons/materials for implementation, and are fighting an internal conflict between their preconceived structure of the class and a reform classroom. The second caricature is the Growing Reformist, and it represents the teachers who have long been traditionalists, but have accepted the vision of reform mathematics and are implementing the *Everyday Mathematics* curriculum with varying degrees of success. They seek out ways to improve their methods and affirmation of their work. The third caricature is the Distinguished Leader, and it represents the teachers who have successfully implemented the *Everyday Mathematics* curriculum as it is designed. They serve as role models and mentors to other teachers, and they are the most successful in the reform implementation. A summary of the characteristics of the three caricatures is in Table 1.

Based on the sample selected for validation after the caricatures were developed, the vast majority (80%) of the teachers were classified as Growing Reformists. Two teachers were classified as Conflicted Traditionalists. One teacher was classified as a Distinguished Leader. There were five teachers who appeared to have characteristics of a Conflicted Traditionalist and a Growing Reformist. This may be the case where the teachers oscillated between caricatures based on the content taught at a given time. Similarly, one teacher appeared to have characteristics of a Growing Reformist and a Distinguished Leader. All but one of the fifty teachers in the sample were identified as fitting into one of the three caricatures. The one teacher that could not be identified as one of the three caricatures was due to insufficient data in the learning logs. These findings are not inconsistent with Lambdin and Preston's (1995) results.

The Caricatures

The Conflicted Traditionalist. Imogene, a Conflicted Traditionalist, has made an attempt to engross herself in the *Everyday Mathematics* curriculum. She spends time preparing the lessons and materials for the day's activities, but is frustrated by the time it takes. She wonders why the materials are not prepared as part of the *Everyday Mathematics* curriculum or by the IMI staff. Also, she is frustrated because "I have to

Table 1
Summary of Characteristics of Caricatures

	Conflicted Traditionalist (Imogene)	Growing Reformist (Randall)	Distinguished Leader (Patricia)
Generalities	• Attempts to immerse self in the curriculum • Fighting internal conflict between preconceived structure of the class and a reform classroom	• Traditionalist but has accepted reform instruction and is committed to implementing curriculum and having success • Seeks out ways to improve methods and affirmation of work	• Successfully implements curriculum as it is designed • Believes in philosophy of reform curriculum • Throws self into curriculum • Serves as role model and mentor to other teachers
Preparation Time	• Frustrated by amount of time it takes to prepare the lessons	• Puts in the necessary preparation time for lessons, but readily admits frustration due to amount of preparation, but yet confers with other teachers about their use of the curriculum	• Spends great amount of time preparing lessons and for the day's activities • Understands the time it takes for students to work through and develop concepts
Classroom Focus	• Focus is on students' satisfaction in the class • Becomes frustrated when students are confused with learning a new idea • Does not allow students to work through their discourse to achieve understanding	• Acknowledges the value of student accountability • Often has students explain their solution process to the class	• Students' understanding is the driving force behind the lessons • Verbalization of how students arrived at an answer is significant
Classroom Structure	• Routine is of utmost importance	• Recognizes the importance of cooperative learning and tries to incorporate it into class	• Follows the reform curriculum but is not bound by it • Allows students' inquisitiveness to guide lesson down another learning path • Values cooperative learning in classroom, and views it as an integral part of the learning process
Manipulative Use	• Acknowledges manipulatives are valuable learning tools, but too quickly gives up or avoids implementing them • Realizes exploration time is necessary when introducing new manipulatives, but yet does not incorporate this into lessons	• Appreciates the importance of the use of manipulatives in lessons and integrates them into lessons • Does not always go smoothly with the students but continues to include them in lessons • Works to improve manipulative inclusion by conferring with other teachers as to their methods	• As manipulatives can be a distraction to the lesson if students are exploring them and familiarizing themselves with them as opposed to focusing on the lesson, allows ample amount of time for exploration with them before developing the lesson
Potential Growth and Successful Implementation	• Tries more of the reform curriculum pieces, but the belief they will make a difference has not yet accompanied the curriculum changes	• Reflects on how lessons go and makes notes for future use • Seeks out advice and affirmation from others using the curriculum • Willingness to thrust self into the curriculum by accepting its philosophy in addition to continually seeking out of advice and affirmation for methods	• Assesses self in addition to students • Reflects on how the lessons go during class and what could have been better • Takes note of what could be different and vows to make the changes in the future

buy and prepare a lot of materials out of my pocket. I have decided to get a second job to afford the materials I must purchase from my own money."

Imogene becomes frustrated when the students are confused with learning a new idea. She often does not allow the students to work through their discourse to achieve understanding. "The kids were really confused by lattice multiplication. So, I finally told them that on their homework they could do the problems any way they wanted." Rather than attempting to let the students reason through their confusion, Imogene allows the students to avoid the discourse, which is vital to their learning process and achieving understanding. This avoidance by Imogene is in conflict with the recommendation of student discourse in the *Professional Standards for Teaching Mathematics* (NCTM, 1991).

Imogene's focus is on the students' satisfaction in the class. She wants her students to avoid frustration, so she intercedes before this occurs. However, rather than giving them access to the tools for them to achieve some level of understanding, she takes a more traditional perspective. "If there is something they do not understand, I can point to the various elements of the problem to show the steps." Again, this is directly in conflict with NCTM's (1991) *Professional Standards for Teaching Mathematics*, which encourages the promotion of student discourse in order to make sense of mathematical ideas.

Although Imogene acknowledges that manipulatives are valuable learning tools, she too quickly gives up or avoids implementing them in her class. She realizes exploration time is necessary when introducing new manipulatives, but yet, she does not incorporate this into her lessons. "I distributed attribute blocks to the students for use in solving problems, but the kids were not getting it. So, I collected the blocks and walked them through the problems on the overhead projector. Attribute blocks are a great tool, but we should also recognize them as possible distractions."

In Imogene's class, routine is of utmost importance. "Routine is very important for the teacher and the students." Imogene uses the *Everyday Mathematics* curriculum but not always necessarily the way it is intended. "I have not been using several of the materials and activities as they are designed. They are just so time consuming, although I see how they are essential for me and my students." Imogene recognizes the importance of the inclusion of the activities as designed, but she is not yet able to relinquish control of what she visualizes as the appropriate routine for the class.

Imogene continues with her internal conflict. She wants to accept the reform curriculum wholeheartedly, but she is still clinging to her traditional background. With the reform curriculum, "For some reason I feel like more and more students are left behind." She tries more of the *Everyday Mathematics* pieces, but the belief they will make a difference has not yet accompanied the curriculum changes. This results in her conflict.

The Growing Reformist. Randall, a Growing Reformist, has accepted reform mathematics instruction and is committed to implementing *Everyday Mathematics* and having success. He puts in the necessary preparation time for lessons, but he readily admits, "Sometimes I get frustrated because there is so much to plan for each lesson." Yet he remains dedicated, and he confers with other teachers about their use of the curriculum.

Randall appreciates the importance of the use of manipulatives in lessons, and he integrates them into his lessons. It does not always go smoothly with the students but he continues to include them in the lessons. He works to improve their inclusion by conferring with other teachers as to their methods.

Randall recognizes the importance of cooperative learning and tries to incorporate it into his class. "It is amazing to observe them working in groups and figuring things out for themselves." Randall concedes the work is often a challenge for the students and has found that, "When they work in groups they do better." In addition, Randall acknowledges the value of accountability. Within the groups, the students explain their ideas, and then Randall often has the students explain their solution process to the class.

Randall is growing as a reformist. He thoroughly prepares the lessons and activities as the curriculum intends. However, Randall admits "I feel attached to my manual, but getting more comfortable with the curriculum will help." Randall reflects on how the lessons go and makes notes for future use. He seeks out advice and affirmation from others using the curriculum. Because of Randall's willingness to thrust himself into the curriculum by accepting its philosophy, in addition to his continual seeking out of advice and affirmation for his methods, he has earned his title Growing Reformist.

The Distinguished Leader. Patricia, a Distinguished Leader, has thrown herself into the *Everyday*

Mathematics curriculum. She believes in the philosophy of reform curriculum. She spends a great amount of time preparing the lessons and for the day's activities. She understands the time it takes for students to work through and develop the concept at hand. The understanding of the concept does not take place overnight and each of the pieces of the *Everyday Mathematics* curriculum serves a purpose in the development. She readily admits, "All of it is very time consuming but wonderful, and I am seeing more and more that spiraling works."

In Patricia's class, the students' understanding is the driving force behind the lessons. As manipulatives can be a distraction to the lesson if students are exploring them and familiarizing themselves with them as opposed to focusing on the lesson, Patricia allows an ample amount of time for exploration with them before developing the lesson. "I feel I need to give the students plenty of time exploring with the manipulatives whenever we have not used them before."

Although Patricia follows the *Everyday Mathematics* curriculum, she is not bound by it. She allows the students' inquisitiveness to guide them down another learning path. For example, in an activity in which students were using geoboards to explore making shapes, a student shouted out that he had made a symmetrical shape. Out of this pronouncement, an entire lesson on symmetry evolved.

Patricia realizes the answer is not necessarily what is of greatest importance, but what is significant is the verbalization of how students arrived at an answer. "I think it is very important I allow students to explain how they got their answers even though this takes quite a while. It is interesting how well some can explain their thinking, while others get the right answer but cannot verbalize it." Patricia places such value on the verbalization of the students' thinking process she includes oral assessments in her class.

Patricia values cooperative learning in her classroom, and it is an integral part of the learning process. The students recognize Patricia's emphasis, and they flourish in the process. "I am so pleased with how the students cooperate with each other while working with partners and in small groups."

Patricia continues to grow as a teacher. She assesses herself in addition to her students. She reflects on how the lessons go during class and what could have been better. She takes note of what could be different and vows to make the changes in the future. Because of Patricia's willingness to allow the students' understanding and inquisitive nature impact the lesson, she continues her development as a teacher and affords her students greater learning opportunities.

Discussion

The three caricatures are not meant as an exhaustive classification by any means. They are based on a limited number of teachers, and certainly not all teachers fit neatly into one of the three caricatures. It is possible a teacher may be a Growing Reformist when teaching measurement and a Distinguished Leader when teaching geometry, or a Distinguished Leader when teaching fractions but a Conflicted Traditionalist when teaching division.

The traits of the caricatures are an exaggeration in order to emphasize the differences between the teachers, and to emphasize the similarities within classes of the teachers. Since the study is based on a limited number of teachers for a period of one year, it is unclear how the teachers will grow as time progresses. Will Imogene work through her conflict and become a Growing Reformist? The conflict a teacher experiences between how to best teach a subject and the simplest way to teach and maintain control of the classroom affects teachers' adaptation to curriculum implementation (Richardson, 1990). Imogene will grow only if she can resolve her ongoing internal conflict. Will Randall grow into a Distinguished Leader? Although some teachers who initially were Conflicted Traditionalists began to show characteristics of Growing Reformists throughout the year, at this point, we have no data that clearly indicates that this evolution occurs or if it is even a linear progression.

Lambdin and Preston (1995) found no data to indicate that a Frustrated Methodologist or a Teacher on the Grow would evolve into a Standards Bearer. They also acknowledge that a teacher may act as a Standards Bearer for a unit that is extremely familiar but then a Teacher on the Grow for a topic that is less familiar.

As the classification of the teachers relied on the writings in the learning logs, it is possible some teachers are not labeled correctly. For instance, with the vast number of teachers identified as Growing Reformists, one wonders how many of them may be Distinguished Leaders, but were not identified as such due to lack of data in the learning logs. These teachers may not have identified the times they mentored colleagues or made note of ways to improve the lessons in the future.

Implications

Mathematics classrooms must continue to evolve to meet the *Standards*, while teachers strive to integrate content and pedagogy so students will have a greater opportunity for the construction of mathematical understanding. Research suggests teachers' content knowledge has a positive effect on students' learning gains (Monk, 1994). In addition, students whose teachers have a solid background in the content area they are teaching have outperformed their peers by approximately 39 percent of a grade level in math (Educational Testing Service, 2000). Whether the IMI teachers' content knowledge affected their implementation of the reform curriculum is unclear. In several learning logs, teachers said, "I had to review a few ideas before the lesson as I was a little rusty," or "I hope I'm teaching this correctly since I have little background in this topic." However, there was no recurring pattern to the comments, and they were not specific to any class of teachers. Still, increased content knowledge may increase the teachers' comfort level in implementing the lessons and teaching their students. In response to a need for increased content knowledge of teachers, the IMI workshops during the academic year include activities designed to increase content knowledge in addition to making connections to the *Standards* and the reform vision of mathematics education.

Another piece of the puzzle is pedagogical content knowledge. Shulman (1986) has defined pedagogical content knowledge as "the ways of representing and formulating the subject that makes it comprehensible to others" and it "also includes an understanding of what makes the learning of topics easy or difficult" (p. 9). It may be that the IMI teachers' pedagogical content knowledge affected their implementation of the reform curriculum. In some learning logs, teachers said, "I found out at the IMI workshop I had been teaching the lesson wrong," or "I hope I'm teaching this right." These comments appeared more among the Conflicted Traditionalists and Growing Reformists than Distinguished Leaders. Again as with content knowledge, increased pedagogical content knowledge may increase the teachers' comfort level in implementing the lessons and teaching their students. In support of the teachers, the log readers, IMI staff, and mentors make themselves available for support. Additionally, the IMI workshops include discussions of the implementation of the *Everyday Mathematics* lessons.

The academic background and teaching experience of the teachers are unknown to the researcher except for a few revelations in the teaching logs. As both of these pieces influence the teachers' content knowledge, pedagogical knowledge, and pedagogical content knowledge, future research should include the examination of the relation (if one exists) between academic background (degree, major/minor) and caricature classification as well as teaching experience (number of years, types of curriculum, grade level) and caricature classification.

As one of the goals of this project is to build leaders, it is important to document the reflective teaching and activities the Distinguished Leaders have exhibited as well as bridge the gap between the Growing Reformists and Distinguished Leaders. Identifying characteristics of Distinguished Leaders and the types of reflective practices they undertake and disclosing this information may help the Growing Reformists become Distinguished Leaders. Additionally, this disclosure to others implementing reform curriculum may help them avoid some obstacles, as well as develop into leaders and become mentors to other teachers.

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[1] A Title I school receives Title I money, the largest single federal source of funding for education. Title I funds are intended to ensure that all children have an opportunity to receive a high-quality education and achieve grade-level proficiency. The funds help students who are behind academically or are at risk of falling behind.

"Natural Philosophy" as a Foundation for Science Education in an Age of High-Stakes Accountability

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Science curriculum and instruction in K-12 settings in the United States is currently dominated by an emphasis on the science standards movement of the 1990s and the resulting standards-based high-stakes assessment and accountability movement of the 2000s. We argue that this focus has moved the field away from important philosophical understandings of science teaching and learning that have their roots in the history of both learning theory and scientific discovery. We offer a philosophical argument, as well as a model for implementation, grounded in the 19th century notion of "natural philosophy," as well as Dewean progressivism and Piaget's notion of reconstruction through rediscovery, for the important place of the history of science in modern science education. We provide curricular examples of this model, as well as a discussion of how it might be implemented as part of teacher education. We focus our discussion on the elementary and middle school grades, because teachers at these levels tend to have more limited science content knowledge than their secondary school peers, making them more dependent upon curricular materials and thus more heavily influenced by curricular reforms.

Modern K-12 science educators in the United States pay relatively little attention to the philosophy of science, and even less attention to the history of science, in either their curricular or instructional practices. The same can largely be said for the university preparation of elementary and middle school teachers of science. This omission is strikingly clear in today's sociopolitical climate as both new and veteran teachers struggle with the curricular and pedagogical pressures of high-stakes testing and accountability. Increasingly, the focus of preparation for teachers in undergraduate preservice programs, school-sponsored in-service programs, and even in graduate programs for professional teachers, centers on the standards-based reforms of the past 15 years. In science education, this initially meant adherence to the documents developed by the American Association for the Advancement of Science (1994), Rutherford & Alghren (1991), National Science Teachers Association (NSTA, 1996) and the National Research Council (1996, 2000), but more recently has led to a growing reliance on state science standards and benchmarks for the state in which the preparation program is situated. Among other implications of this trend in science education, perhaps the most troubling is the resulting teacher-as-technician model for how to engage elementary and middle grade children in science learning, a model that takes preparation for standards-based state assessments as the goal of science education.

While we do not object to science standards, per se, we believe that the current focus provides an impoverished view of what makes science such a robust epistemology. The current standards-based approach to science education, as implemented in schools and districts around the country, can best be conceptualized as an attempt to promote knowledge of discrete science benchmarks loosely clustered into strands, plus the ability to perform some iteration of a "scientific method." While these are both necessary components of science education, they fall short of representing the characteristics of science that are responsible for much of what we experience in modern society. Instead, we advocate the development of a systematic understanding of the philosophy of science and the historical development of science through a rediscovery-based curriculum model. We believe such a model is valuable both for science teacher education and for students' science learning. This approach draws on major historical experiments that are the foundation of the respective fields of physics, chemistry, biology, and Earth science.

Natural Philosophy and the Rise of Kitchen Science

While inquiry into the natural world can be traced to mankind's earliest writings, and while we acknowledge the contributions of many cultures to our current, cumulative scientific understanding, the modern roots of what we today call natural science are often traced to the natural philosophy movement beginning in the late 17th and early 18th century. Natural philosophy was the study of nature with special attention given to the structure, function, and interactions between natural objects. Both Francis Bacon and Isaac Newton couched their work in terms of natural philosophy, with Newton titling his most famous book *Philosophiæ Naturalis Principia Mathematica (The Mathematical Principles of Natural Philosophy)* (1687). Thus, natural philosophy can be seen as influencing the development of modern mathematics as well as the modern sciences. A central feature of these early writings in natural philosophy was the equal emphasis placed on the properties of natural objects being explored and the processes and tools being used to make those observations. Thus, a similar argument can be made for the inclusion of more history and philosophy of mathematics in the modern math curriculum as a way of promoting mathematical problem solving.

It is notable that these initial forays into outlining natural philosophy viewed content and process as inseparable and equally important and contained none of the modern debate over the relative emphasis that should be placed on these two aspects of science teaching. Bacon's *Of the Proficience and Advancement of Learning, Divine and Human* (1605), for example, argued for the need to adopt and codify new methodologies grounded in experiment and observation. Such proposals were in stark contrast to Aristotelian philosophical reflection, which described the world rather than demonstrated how it actually functioned. Until the rise of the natural philosophy movement, philosophical argument was considered the highest form of explanation of natural phenomena and did not require experimental proofs.

On a more popular level, during the Early Modern period, the term natural philosophy came to be understood as "the workings of nature," and emphasized the idea that common experience could be understood and interpreted through basic observation and experimentation. Still, even among lay natural philosophers, the dual goals of understanding the workings of nature and understanding the proper use of scientific tools and processes for making such observations were maintained.

Science education for children grounded in the tenets of natural philosophy is by no means a new approach. As early as 1761, the English publisher John Newbury (1713–1867), who is considered the founder of modern children's literature, published *The Newtonian System of Philosophy Adapted to the Capacities of Young Gentlemen and Ladies*, under the pseudonym Tom Telescope. Newbury's book "explained by familiar objects, in an entertaining manner" the basic principals of Newtonian physics. The book is important both as the first published attempt to use concrete examples in the teaching of science to children and, more broadly, as a significant contribution to the establishment of writing for children as a genre separate from adult books.[1]

By the beginning of the 19th century, a substantial collection of writings in natural philosophy for children had emerged. In books such as Sir David Brewster's *Treatise on the Kaleidoscope* (1819), Jeremiah Joyce's *Scientific Dialogues* (1829), John Ayrton Paris's *Philosophy in Sport* (1827), and Michael Faraday's *A Chemical History of the Candle* (1860), newly discovered principles of natural science were introduced to children. At the time, this writing was not viewed as part of the curriculum of formal education, but rather, was the beginning of the tradition that later became known as "kitchen science"—a hands-on approach to demonstrating scientific principles in informal contexts, done with the simplest possible materials, often, supplies found in the kitchen or around the house.

The 19th century tradition of natural philosophy was not just a set of activities, but also a way of viewing the world. In this context, natural philosophy was believed by authors such as Brewster, Joyce, Paris, and Faraday to reveal the mechanisms upon which physics, chemistry, and the natural world functioned. Their approach focused on uncovering and demonstrating the relationships between the different natural phenomena that were being explored. As such, it was actually quite different from much of the later "kitchen science" that became popular in the mid-20th century, with figures such as the television star Mr. Wizard (Don Herbert) and, more recently, Bill Nye the Science Guy. For example, Michael Faraday, in his book *The Chemical History of a Candle*, which was originally given as a series of children's Christmas

lectures at the Royal Institution of London beginning in 1860, explained in Lecture I:

> There is not a law under which any part of this universe is governed which does not come into play, and is touched upon in these phenomena. There is no better, there is no more open door by which you can enter into the study of natural philosophy, than by considering the physical phenomena of a candle. (p. 5)

It is clear that Faraday believed that simple models such as those provided by a burning candle could provide the best means of introducing learners to the fundamentals of science, as well as to how those fundamentals were interconnected, and how such discoveries were made. Although simple on the surface, such models provided affordances for profound understanding of complex ideas and relationships. Though he experimented with other more complicated models, Faraday returned throughout his career to the simplicity of basic models such as a burning candle, claiming that the more complicated models "could not be better, were they even so good" (p. iv).

In France, natural philosophy as pedagogy was codified in the early 1890s with the publication of Albert Good's three-volume collection of hands-on science experiments for children known as *La Science Amusante*.[2] Hugely popular, these books were eventually translated into English and published both in England and the United States. At about the same time, the French scientist Gaston Tissandier produced a one-volume encyclopedia of science and scientific experiments titled *Popular Scientific Recreations* (1890).

During the first half of the 20th century, the progressive education movement in the United States continued to promote the core ideas of natural philosophy—the study of natural objects and phenomena, with special attention given to their structure, functions, interactions, and relationships, as well as to the processes used in making these discoveries—while shifting the location of instruction from the informal to the formal school setting. At John Dewey's University of Chicago Laboratory School, his curriculum modeled the integration of all subject areas, with science playing a central role. Dewey introduced science at the elementary level through shopwork (mechanics) and cooking (chemistry and measurement). He believed that "handwork" was a key to students obtaining the skills they needed to learn science. As he explained:

> Science is largely of an experimental nature. It is a fact that may not have come to your attention that a large part of the best and most advanced scientific work involves a great deal of manual skill, the training of the hand and eye. It is impossible for one to be a first-class worker in science without this training in manipulation, and in handling apparatus and materials. (Dewey, 1907, p. 120)

To this end, Dewey's approach to science education took the philosophy that Good, Faraday, and others had practiced in the "parlor," and demonstrated how it could be applied in the context of formal schooling. It is instructive to listen to Dewey describe his lab school's science curriculum 100 years after the fact, and to compare this to what many modern progressive science educators continue to advocate (and rarely achieve).

> Last year a good deal of work was done in electricity (and will be repeated this year), based on the telegraph and telephone—taking up the things that can easily be grasped. In mechanics they have studied locks and clocks with reference to the adaptation of the various parts of the machinery. All this work makes a most excellent basis for more formal physics later on. Cooking gives opportunity for getting a great many ideas of heat and water, and of their effects. The scientific work taken up in the school differs mainly from that of other schools in having the experimental part—physics and chemistry—emphasized, and is not confined simply to nature study—the study of plants and animals. Not that the latter is less valuable, but that we find it possible to introduce the physical aspects from the first. (Dewey, 1907, pp. 124–125)

Despite the work of Dewey and other progressive educators, science education grounded in natural philosophy had fallen out of favor in the United States by the 1920s. As classical liberal curriculum theory focusing on the promotion of models of efficiency began to take hold in the schools (Beyer & Liston, 1996) science curriculum became more factually oriented and less investigative.

Kitchen science reemerged in the mid-20th century, due in large part to the work of Don Herbert, who, starting in the 1950s, produced the children's science television program, *Mr. Wizard*. Herbert drew largely upon materials that had been published in late 19th century in magazines such as *Scientific American* and the French scientific journal *Le Nature*. These journals had, at that time, regularly produced columns that provided a basic introduction to scientific phenomenon for children.

Herbert adopted these activities using more updated, but still very basic materials. While in some ways Mr. Wizard's approach to discovery learning of core science principles harkened back to Faraday's Christmas lectures, in other ways, the approach failed to capture key elements of the natural philosophy pedagogy. Most notably, an emphasis on understanding the connected nature of diffuse scientific phenomena, couched in a broader philosophy of science, was largely absent from Mr. Wizard's presentations. Instead, the emphasis was on isolated phenomena, preferably of the kind resulting in a surprising fizz, bang, or pop.

From Sputnik to State Standards

A fundamental shift in the philosophy that guided science education in the United States occurred with the launch of Sputnik 1, the world's first artificial satellite, on October 4, 1957, marking the start of the "space race" between the United States and the Soviet Union. At the heart of this shift was a move away from both Deweyan Progressivism with its focus on applications of knowledge in "real-world" contexts, and classical liberalism with its focus on educational efficiency. Instead, there was a turn toward curriculum reform that emphasized the "structure" of each scientific discipline. Driven by research scientists familiar with university science instruction, emergent curricula attempted to restructure K-12 science education to align it with science as taught in the universities. When viewed in its sociopolitical context, it is understandable why these post-Sputnik era curricula de-emphasized the place of the history and philosophy of science in science education. These educational reforms were part of a broader national agenda to move beyond the past, and create a future in which the United States would be the dominant global force due to its superior knowledge of science and technology, as well as its democratic values.[3]

Notably, at about the time that the post-Sputnik education reforms were taking place, the work of the Swiss psychologist Jean Piaget was beginning to be widely disseminated. Piaget argued that learners construct knowledge and meaning for themselves in unique and individual ways, framing intellectual development as a combination of hereditary and environmental factors. For Piaget, knowledge was invented and reinvented as children interacted with the world around them. In his book *To Understand is to Invent* (1973), Piaget argued that "to understand is to discover, or reconstruct by rediscovery" (p. 20).

On a practical level, Piaget's theory implies that for children to learn and truly understand concepts about a topic such as electricity, they would be best served by semi-structured tasks that ask them to reinvent and discover the concepts for themselves, much as early scientists had done when making their original discoveries. While this approach has practical limits as children grow older and study increasingly complex and theoretical science topics, at the elementary and middle grades, such an approach is quite feasible. Thus, Piagetian constructivism, while providing additional theoretical support for the activities of the earlier natural philosophers, as well as for Deweyan progressive educators, was largely at odds with the post-Sputnik structural emphasis in science curricular reform.

Throughout the 1960s and 1970s the National Science Foundation funded the development of a number of new curricula from the "structures of science" paradigm.[4] The structural emphasis approach overlapped with and then gradually gave way to the rise of the national standards movement in the 1980s and 1990s (National Research Council, 1996; Rutherford & Alghren, 1991). Science curriculum began to place an increased emphasis on models of open inquiry (Steffe & Gale, 1995). In this approach, students were asked to discover or construct essential science concepts for themselves and to learn science more or less as scientists do science (Jonassen, 1991). This approach gained favor among many science educators despite concerns that were raised about expert–novice differences between trained scientists and science students, and the cognitive load of such an approach (Klahr & Nigam, 2004).

More recently, as the current wave of state standards gained prominence in the 2000s, these documents tended to de-emphasize and simplify inquiry into a narrow notion of practicing the scientific method,

along with an emphasis on teaching discrete science benchmarks loosely clustered into strands. Thus, we have arrived at the point of a tension in science curriculum studies between open inquiry, as supported by many science educators, and minimal inquiry, as practiced by most elementary and middle school science teachers as they follow state standards and pacing guides. In the following section, we describe a curricular model that is more closely aligned with the natural philosophy approach and Piaget's notion of knowledge reconstruction through rediscovery. We perceive this approach as a potentially fruitful middle ground between the extremes of open and minimal inquiry.

Teaching Science Through Natural Philosophy and Reconstruction Through Rediscovery

While the structural emphasis was most common in science curricular reform through the 1970s and 1980s, publications such as *Rediscovering Astronomy* (Provenzo & Baker Provenzo, 1980) and *Rediscovering Photography* (Provenzo & Baker Provenzo, 1979) provided supplemental curriculum materials for middle school students that were grounded in natural philosophy and historical science content. The goal of these materials was to help teachers implement an integrated model of teaching history and science through experiments, historical content, and major discoveries in the fields of astronomy and photography.

As an example, *Rediscovering Astronomy* outlined the historical development of the field of astronomy while engaging the student in a series of observational experiments that were part of the historical foundation for discovery in the field. Beginning with the creation of an Egyptian sundial, the students moved on to construct and use early navigational tools, including a medieval quadrant or astrolabe, followed by a sextant. The remainder of the curriculum focused on magnification techniques that were foundational to the development of modern astronomy. Students constructed and explored magnifying lenses, and then used these lenses to build a simple refracting telescope. Finally, students built and made observations with a functional Newtonian reflecting telescope.

Each experiment included historical background and period illustrations and could be done with easily obtained and inexpensive materials, following Faraday's notion of teaching complex ideas through simple models. Dewey's notion of the importance of "handwork" was also prominently featured, such as when students practiced methods of constructing precision "telescoping" paper tubes. Explicit attention was given to the interrelated and cumulative nature of the experiments, both conceptually and methodologically, as well as how these developments were part of a larger historical scientific process.

One potential shortcoming of the rediscovery approach is that in the "redoing" of earlier experiments, a known answer will result. This may reinforce the idea, held by many students, that science is the study of things that are already known rather than the exploration of questions that are yet unknown. If restricted to rediscovery, students will be limited in terms of discovering things for themselves and asking unique and original scientific questions. We believe, however, that a rediscovery model is foundational in nature and provides students with basic tools and models for further exploration of the natural world. Beginning with rediscovery does not impose a limit on the freedom of students to explore and discover on their own. Following from Piaget, it can be argued that beginning with rediscovery of fundamental science principles actually strengthens the child's ability to advance to more complex problem solving. Furthermore, the rediscovery approach can encourage students to move beyond experiments to test variations and extensions as part of a process of personal exploration and discovery.

More recently, we have attempted to refine this curricular model to maintain an emphasis on the natural philosophy approach and reconstruction through rediscovery while also considering how topics for rediscovery can be aligned with national and state science standards (Buxton & Provenzo, 2007). The model is based on presenting triplets of activities for each major science concept, as well as background material including both historical and modern perspectives. It is still conceptualized as a supplementary rather than a replacement curriculum. We do not believe that a curriculum based on natural philosophy and historical examples of reconstruction through rediscovery is viable as the complete science curriculum given the range of topics covered in most state science standards. Instead, it is meant to provide teachers with a way to engage their students in selected topics in a way that highlights the value of considering the history and philosophy of science.

Our model subdivides the four main science disciplines of physics, chemistry, biology, and Earth/space

science into between seven and nine key concepts each. For example, the chemistry module is divided into the topics of: measurement in chemistry, atoms and molecules, matter, bonding, temperature, pressure, and fuels. Each topic contains a triad of activities. Each triad consists of a general discussion of the central concept, with connections between current understandings of the concept and the key historical work that led to the construction of this understanding. To use the example of the topic of pressure from the chemistry module, the triad begins with examples of where students encounter gas pressure in their daily lives.

Historical connections are then made through the activities as students reconstruct through rediscovery Otto Von Guericke's 17th century experiments with creating vacuums (the "Magdeberg Sphere"), a burning candle experiment similar to Jacques Charles' experiments studying the gas law relationships, and Alexander the Great's 4th century BC experiments using a diving bell modeled using a Cartesian diver. Concluding questions for each triad push the learner toward making connections across the three activities and to modern day applications of the key concepts. For example, on the topic of color and vision, students construct a thaumatrope ("wonder-turner" in Greek), a devise first designed by the early 19th century scientist, John Ayrton Paris, as part of his study of the physiology of the eye. He invented the thaumatrope to demonstrate his theory that the retina literally took "snapshots" of images and transferred them to the brain. The thaumatrope became more than a research instrument to study the persistence of vision, however, as refinements and elaborations of this device—the phantascope followed by the zoetrope—led to the invention of the first motion picture machines.

Thus, our model attempts to highlight what we find most compelling about the work of early scientist/educators like Brewster, Joyce, Paris, and Faraday—the idea that natural philosophy is not just a set of activities, but also a way of viewing the world. While this revised model of reconstruction through rediscovery may still be more limiting than full open inquiry when it comes to students' personal exploration and creativity, we believe that gaining this historical basis actually provides a strong foundation for students' further creative pursuits with science inquiry. Indeed, many of the activities in our model conclude with open-ended questions that direct students to create their own scientific investigations on related and new topics.

Using the Natural Philosophy Model of Science Education for Teacher Education

Explicit in the curricular model we have outlined earlier is the belief that the fundamental principles of science, as well as an understanding of their connected nature, are readily accessible to both children and beginning teachers. Experiments that would have required specially crafted tools in previous centuries can today be carried out with the resources found in most hardware or grocery stores. By conducting rediscovery experiments such as the ones described earlier, elementary or middle school children and their teachers can come to see science in both its historical and modern context, while building an understanding of the structures, functions, interactions, and relationships of natural objects and phenomena. The model of natural philosophy and reconstruction through rediscovery pushes learners to see science as more than a loose collection of standards and benchmarks, but rather as a set of interconnected principles with historical roots for explaining phenomena observed and experienced in the natural world. In doing so, students are provided with the foundational knowledge that will allow them to become more creative and engaged scientific inquirers and learners.

We have been using this model with our preservice elementary teachers during their science methods course for the past two years, and have been collecting observational data in our own classroom and in the preservice teachers' field experience classrooms, as well as through the teachers' science reflection journals. While a more systematic study of these preservice teachers' evolving beliefs and practices regarding science teaching will be forthcoming, preliminary and anecdotal results seem to indicate that preservice teachers in the course gain an increased understanding of science as a process of discovery with historical roots and that they enjoy teaching the historical experiments to the students in their field experience classes. One quote from a science journal that led us to think that at least some preservice teachers were finding value in this model was the following:

> I used to think that science was just lasers and rockets and high-tech stuff. I knew I didn't understand it because I knew I didn't know how any of those things work. The science is all hidden in microchips and electronics. But I learned that science can also be as simple as a burning candle. A lot of what scientists know now comes from

> those historical experiments that anyone can understand. When I made the wonder turner with the kids in my field experience, they had a great time, they learned science and they learned history. Ms. A [the classroom teacher] was very happy with the lesson and so was I. (preservice teacher science journal 11/4/07)

While the curricular and pedagogical implications of Deweyan progressivism and Piagetian constructivism are not new to science education, this would seem to be a timely historical moment to consider their collective potential to enhance both science teacher education and science teaching in our elementary and middle school classrooms. We see our argument as an important counterpoint to the growing influence of the standards and accountability movement on curricular and instructional decision making.

The Influence of the Standards Movement and High Stakes Accountability

Our argument for a more historically rooted science education raises important questions about the limitations of the current standards-based curricular models being promoted and implemented in the United States. While we are neither opposed to standards being set in the curriculum nor to those standards being assessed in a systematic way, we question the extent to which a rich epistemology of science, including both its cognitive and cultural components, can be meaningfully assessed within the current curricular paradigm.

We find particularly troubling the translation that typically results when the national standards migrate to state- and district-level implementation. So, for example, while the national science education standards (NRC, 1996) dedicate five of eight categories of content standards to topics other than traditional disciplinary content areas (e.g., unifying concepts and processes in science, science as inquiry, science and technology, science in personal and social perspectives, and history and nature of science), at the state and local level, this focus is typically turned squarely back to traditional disciplinary content knowledge, with all remaining topics lumped into a handful of standards and benchmarks about "inquiry" and/or the "nature of science."[5] Mention of the history of science is typically absent. That these state standards then serve as the frameworks for state assessments means that the foundational model of science learning that we advocate has little likelihood—or means—of being adequately assessed within the current implementation of the science standards in most U.S. schools. We consider the case of several specific state science assessments.

In the case of Florida, for example, the Florida Comprehensive Achievement Test assesses students on eight different strands of science. Three of these focus on the physical sciences, two on the life sciences, two on the Earth and space sciences, and one on the nature of science. However, the nature of science strand assesses only a narrow set of ideas about inquiry, the control of scientific variables and basic experimental design. The history of science, philosophical issues about the nature of science, and broader epistemological issues are absent.

Similar situations can be seen in states such as Texas and California, which along with Florida and several other of the more populated states are well known to heavily influence both the design and the adoption of textbooks for others states throughout the country. In the case of Texas, the Texas Assessment of Knowledge and Skills (TAKS) assesses students on five science objectives: the nature of science; organization of living systems; interdependence of organisms and the environment; structures and properties of matter; and motion, force, and energy. Similar to the case of Florida, the Texas assessment of the nature of science objective is largely limited to formulating testable hypotheses, making precise measurements, and organizing and evaluating data. Again, the more foundational aspects of the history and nature of science are omitted from the TAKS assessment. As curricula are revised to improve alignment with the assessment measures, the spaces for even supplemental curricula that highlight natural philosophy and reconstruction through rediscovery become increasingly constrained.

Indeed, assessments of the kind that have gained prominence in recent years are hard-pressed to evaluate the types of learning that we feel are most important for gaining scientific literacy. Lessons in science that focus on the structure, functions, interactions, and relationships of natural objects and phenomena, the cornerstone of what we believe good science teaching should promote, may not transfer well to paper and pencil mass-scored assessments. They do not lend themselves to isolated assessment items, be they multiple choice or constructed response. Rather, we believe that these instructional goals are much better evaluated through performance assessments involving the application and use of scientific tools and

processes. Yet the costs, logistics, and psychometric issues involved in large-scale assessment conspire to make it extremely difficult to implement such assessments on a large scale.

We note, however, that performance assessments are not unprecedented at the state level. Colorado, for instance, implemented a statewide 4th grade performance assessment on variables influencing the heights of bouncing balls for several years in the late 1990s. Similarly, Louisiana included performance components on its 5th and 8th grade science assessments in the early 2000s. These tasks included the assessment of accurate use of various measurement tools, exploring and documenting the shapes of magnetic field lines, and testing the capability of various circuits to light a bulb. While none of these tasks, as they were designed and implemented, would be considered rich in nature, history, or philosophy of science, they do serve as proof of concept that it is possible to include performance assessments as part of state-wide accountability testing. The fact that both of these attempts were phased out after a few years, however, speaks to the sizable challenges as well.

The assessment challenge to the model of teaching we propose is further exacerbated by the growing instructional response to high-stakes accountability plans that most states now have in place. As the policy consequences of students' state-level standardized test performance continue to mount for students (potential grade retention), teachers (merit pay and/or public censure), schools (school grades), and districts (modifications to state funding), the pressure on teachers and school-level administrators continues to increase. Thus, it is no wonder that elementary and middle grade science teachers, many of whom have weaknesses in their own science content knowledge (Abd-El-Khalick, Bell, & Lederman,1998), may become more conservative in their science instruction, spending more and more time on explicit test preparation and less and less time on robust scientific discovery. For teachers in urban school settings with "at risk" student populations, this tendency is likely to be even more pronounced (Lee, Maerten-Rivera, Buxton, Penfield, & Secada, 2009).

As state-level high-stakes testing seems unlikely to lessen in importance in the near future, we see teacher education (as well as the education of school-level administrators) as the best way to promote more philosophically grounded science teaching. Teachers must become convinced (to such a degree that they are willing to place a "high stakes bet") that a fundamentally different approach to science instruction, such as the natural philosophy and reconstruction through rediscovery model that we advocate, will provide their students with an understanding of science that will prepare them at least as well for the state assessments as an instructional approach dominated by explicit test preparation.

We recognize that it is one thing for us, as university educators, to advocate historically based experiments and performance assessments (i.e., being able to recreate and explain what happens in a vacuum patterned after Von Guericke's 17th century Magdeberg Sphere), and quite another thing to expect teachers to buck current convention and teach scientific discovery using an interconnected series of explorations grounded in a 200-year-old model of science. Still, for those of us who believe that curricular and instructional models reflective of the natural philosophy of Bacon and Newton, as well as the educational theories of Dewey and Piaget, are more theoretically and conceptually sound than the currently popular approaches, we have a certain ethical responsibility as teacher educators. We must help elementary and middle grade science teachers gain the knowledge, skills, and dispositions necessary to resist theoretically tenuous curricular trends and strive to implement science curricula rich in the foundations of science.

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Authors' Notes

[1] John Newbery is credited with inventing the field of children's literature. While educational texts such as chapbooks and primers were widespread in Europe by the middle of the 18th century, Newbery was the first to develop books that were specifically written for the education and entertainment of children. His 1744 title *A Little Pretty Pocket Book* is widely considered the first modern piece of children's literature.

[2] *La Science Amusante—100 Nouvelles Experiences* by Tom Tit (Arthur Good) with illustrations by Poyet was first published in the French magazine *L'Illustration* and later released in three separate volumes between 1890 and 1893.

[3] For a complete discussion of the curricular reforms of the post-Sputnik era, see Rudolph, J. L. (2002). *Scientists in the classroom: The Cold War reconstruction of American science education*. New York: Palgave.

[4] New curricula in science included work done by the Physical Science Study Committee (PSSC Physics), the Biological Sciences Curriculum Study (BSCS biology), and the Earth Sciences Curriculum Project (ESCP earth science) among others. New programs in mathematics included the University of Illinois Committee on School Mathematics (UICSM), the School Mathematics Study Group (SMSG), and the University of Maryland Mathematics Project (UMMP).

[5] See the state science standards for Florida (http://www.floridastandards.org/Standards/FLStandardSearch.aspx), Texas (http://ritter.tea.state.tx.us/rules/tac/chapter112/index.html), and Virginia (http://www.doe.virginia.gov/testing/sol/standards_docs/science/index.shtml) for typical examples.

Preservice Mathematics Teachers' Ambiguous Views of Technology

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While the nature of mathematics and the nature of science have received much attention, there is a lack of research on the nature of technology. This study sought to investigate preservice teachers' perceptions about the nature of technology and its role in mathematics education and society. Based on two philosophical theories of technology, the author analyzed 22 preservice teachers' philosophy statements on educational technology and in-depth interviews with 5 of them. The findings reveal that the teachers had ambiguous notions about the characteristics of technology, which were contingent on contexts of technology use, human–machine relationships, and other factors. However, in most cases, they had an instrumental view of technology and a technocentric mindset. Although the participating teachers were encouraged to reflect on broad socio-cultural issues associated with technology, most of them did not have a linguistic and conceptual framework from which to examine thoroughly how technology might influence human consciousness. As the educational technology and teacher education communities have broadened their understanding of technology and what it takes for an organizational change, preservice teachers need adequate opportunities to explore the pedagogical, epistemological, ontological, and cultural implications of the educational use of technology.

Introduction and Rationale

The study sought to examine preservice secondary mathematics teachers' perceptions about the nature of technology and its role in mathematics education and society. The author analyzed 22 teachers' philosophy statements on educational technology and in-depth interviews with 5 of them as a means to explore how they understood the characteristics of technology and how it might influence teaching, learning, and daily lives. The rationale for this line of inquiry arose from both an observation of mathematics classrooms as well as research literature.

A few years ago, a high school in California adopted a comprehensive computer-based curriculum called PLATO, including English, mathematics, science, and social studies. At the learning center of the high school, students worked on PLATO algebra modules delivered via the Internet. In the beginning, students enjoyed learning mathematics with PLATO. According to a report in a local newspaper, the program was able to boost students' interests in learning and improved their grades. However, it turned out that more than 80% of the students failed the course at the end.

Research has documented such an unfulfilled promise of technology to improve teaching and learning (e.g., Cuban 1986, 2001). Among the issues related to reforming schools through technology, the education community's assumptions about the nature of technology and the underlying ideologies are examined by a few scholars. Bowers (1988, 2000) discussed a danger of viewing technology as merely a neutral tool and students as Cartesian autonomous individuals. He urged educators to critically examine how technology enforces cultural patterns that contribute to current educational and ecological crises (e.g., commodification of nature and human relationships). Robertson (2003) argued that teachers' and policy-makers' enthusiasm for integrating technology in education was based on a naïve faith in technology. In effect, these scholars' works suggest that it is imperative to investigate education stakeholders' perceptions of the nature of technology because such perceptions can greatly influence their decisions about whether, what, why, and how technology can be integrated in school curricula.

Research on the nature of technology is largely conducted in the fields of Science, Technology, and Society (STS) and technology education. There is a lack of such research in general education, mathematics education, science education, or teacher education. Flick and Lederman (2003) posit that, while the nature of mathematics and the nature of science have received much attention, there is a lack of discussion about the nature of technology. Thus, educators, policy-makers, and other education stakeholders have little chance to be informed of the research and practice related to the nature of technology and its relationships to education.

Therefore, in this study, I sought to understand how preservice mathematics teachers perceived the nature of technology. I summarized their responses to questions such as "what is technology?" "what is the relationship between technology, mathematics, education, and society?" and "how may technology mediate teaching and learning?" This study is significant in that an investigation into teachers' notions of technology will increase our understanding of how teachers consider the human–technology relationship and how they can structure lessons and activities in a technology-supported environment that is conducive to meaningful learning. This study can also shed some light on how we can prepare teachers and students for the 21st century, where technology can exert unprecedented influence on education and social life.

Theoretical Framework

Two theories of technology provide the framework for analyzing the data and guiding the discussion in this study.

Instrumental Theory of Technology

An instrumental view of technology is the most widely accepted view in society. People commonly believe that technology is a tool or device that is ready to serve the purpose of its user. Technology is seen as neutral and apolitical; it is free of values and does not favor any form of politics or society. People subscribing to the instrumental theory of technology will not blame on technology when it is associated with negative consequences in society; technology's misuse by politicians, the military, business, and other sectors is to blame (Pacey, 1983). According to Christians (1997), such an instrumental view of technology is a legacy of Aristotle, who posits that technological products have no meanings in themselves and that technology receives its justification from serving human life.

Feenberg (2002) summarizes the notion of the neutrality of technology in the following four points:

1. Technology is indifferent to the variety of ends it can be employed to achieve. It is unbiased and seen as a pure instrumental means without any embedded culture values.

2. At least in the modern world, technology is indifferent to politics and not prejudiced toward capitalist, socialist, or other types of societies. Technology is not intertwined with other aspects of the society in which it is designed and used. A computer is a computer, and such tool is useful in any social and political context.

3. This socio-political neutrality of technology is usually attributed to its rational character and the universality of the truth it embodies. The development of technology is based on verifiable causal propositions. To the extent that such propositions are true, they can be applied to other social and political contexts. This implies that technology tools will serve the same purposes regardless of the context of its usage.

4. The universality of technology also means that the principles of accessing its characteristics and impact are context independent. Technology is neutral because it stands essentially under the very same principle of efficiency in any and every context. If technology works in a certain place, in a certain time, and under a certain society, then it will work in different places, different eras, and different civilizations (pp. 5–6).

In short, people subscribing to the instrumental theory of technology separate themselves from the tools they are using. Technology has no bearing on human nature; it does not have any ethical meaning in itself.

Substantive Theory of Technology

A few thinkers argue that technology is never a neutral or apolitical tool. It actually represents an autonomous cultural *system* and fundamentally can act to shape human perception and actions. The French sociologist Jacques Ellul (1964) posits that technology has become the defining characteristic of all modern societies regardless of political ideology. The technological society is regulated by *technique*, a term he defines as follows:

> The term *technique*, as I use it, does not mean machines, technology, or this or that procedure for attaining an end. In our technological society, *technique is the totality of methods rationally arrived at and having absolute efficiency* (for a given stage of development) in *every* field of human activity. (p. xxv)

In this definition, Ellul clearly states that technique does not refer to a specific tool or procedure. Instead, he emphasizes *totality* and *system*. To him, technique is a whole sociological and cultural phenomenon, and it is related to *every* factor in human lives.

Moreover, Ellul argues that technology is becoming autonomous; it is going beyond human control, and operates and evolves according to its own logic and norms. He provides examples and shows that in every

aspect of human life—politics, economy, education, entertainment, and so on—our mentality and behaviors are determined by *technique*, as we seek to reach maximum production and performance by means of a set of rational procedures governed by the principle of *efficiency*.

The German philosopher Martin Heidegger (1977) also discusses the autonomous nature of technology. On an ontological level, Heidegger is concerned with the relationship between the essence of human beings and the essence of technology. He posits that technology is not external to human existence; rather, it is intertwined with the existential structure of human beings. With the development of technology in modern societies, he argues that we are involved in a transformation process of the entire world into "standing reserves," which is to say that everything is reduced to being raw materials processed within a technological system. Technology brings about a social and political process. Our engagement in this process would make us subject to a transformation that enables objectification within a technical system, where all, including humans, has become objects.

Both Ellul and Heidegger share the notion that human civilization is becoming more and more aligned with a standard of efficiency intrinsic to modernity and, in this regard, becomes alien to the tradition of social humanism. Technology has been transforming our society to a more technically oriented system where values and questions are re-defined and solutions are directed to technical ones. Substantive theorists urge us to recognize that technology and society are dialectically intertwined; technology has become an environment and a way of life.

Similarly, Don Ihde (1979) posits that we are deeply involved in a "technosphere" within which we are oblivious to the mediating nature of technology. He states:

> Machines become, in technological culture, part of our self-experience and self-expression. They become our familiar counterparts as quasi-others, and they surround us with their presence from which we rarely escape. They become a technological texture to the World and with it they carry a presumption toward totality. In this sense, at every turn, we encounter machines existentially. (p. 15)

Indeed, phenomenologically, we live in the midst of technology. It has become the background of our world; we hardly notice its constant presence. It encloses all dimensions of our relations with the world. Thus, we tend to take it for granted and are unconscious of how technology transforms or mediates our experience.

The Role of Technological Tools in Mathematics Education

The previous discussion of the philosophy of technology focuses broadly on relationship between technology and human beings/society (which is important as our world view affects how we perceive ourselves and how we rationalize our actions). I now turn to specific implications of both instrumental and substantive theories for an investigation of the role of technological tools in development of mathematical knowledge.

According to the instrumental theory of technology, tools play an *external* role in learners' cognitive process. There is a separation of human mind from technology. While technology assists and augments learners' capacity in obtaining mathematical knowledge and skills, it is an independent entity in this process (see Figure 1).

In this scenario, technology is thought of as an external device that can perform calculations, display graphs, and allow manipulation of mathematical objects. Learners are to develop attributes of and relationships within mathematical objects. Learning is a cognitive process that is independent of the technology that augments the learning.

On the other hand, substantive theorists recognize that all human experience is mediated by and structured through technology. Rivera (2005) argued that students embody technology as they engage in a tool-induced process of learning mathematics. In this "instrumentation" process, students internalize technological tools that "furnish a more dynamic form of mediation that enables learners to develop mathematical knowledge" (p. 135), including new modes of mathematical thinking and instrumental actions (see Figure 2).

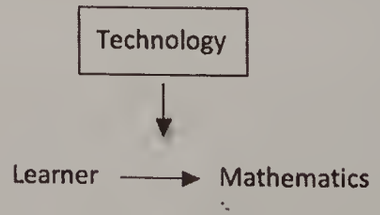

Figure 1. Technology as an external tool to augment mathematics learning.

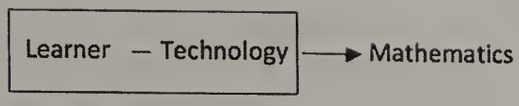

Figure 2. Technology as embodied in mathematics learning.

In this scenario, technology is no longer an external entity. Technology and the learner as embodied become experientially a semi-symbiotic unity, and the technology mediates what and how mathematics is experienced and learned (at the same time preventing learners from accessing the types of activities and mathematics that are not afforded by the particular technology). In this process, the learning activity is an *instrumented* one; when learners appropriate technology in their learning, it becomes an integral part of their thinking, thus the interweaving of instrumental and mathematical knowledge (Rivera, 2007).

In the discussion section, I will elaborate the role of technology in mathematics education in light of the findings of the study. It is my contention that mathematics teachers' understanding of the mediating and substantive nature of technology can help them define the appropriate role of technology in their teaching, which in turn influences students' schooling experience.

Research on Teachers' Perceptions About the Nature of Technology

Little empirical research has been conducted to examine teachers' conceptions of the nature of technology. Most research focuses on teachers' technology use (MacBride & Luehmann, 2008), beliefs and attitudes (Guerrero, Walker, & Dugdale, 2004), and factors influencing technology integration (Baek, Jung, & Kim, 2008). Questions concerning the epistemology of technology are seldom raised by researchers.

Fleming's study (1992) is an exception, which involved a survey of 596 Canadian teachers' views on technology and society. The findings suggested that these teachers overwhelmingly subscribed to an instrumental view of technology. They took an artifact or tool perspective on technology, and the majority held an incomplete view of the nature of technology. Fleming worried that teachers' lack of the socio-political awareness of technology would impede students' development of "technology literacy," a notion that includes the ability to critically reflect on the relationship among technology, society, and education.

Fleming's study is based on a large-scale questionnaire that is a snapshot of teachers' perceptions. The limitation of such a study is its inability to examine the complex systems of teachers' conceptions about technology. In this regard, Ferneding's study (2003) suggested that, upon greater reflection, many teachers had contradicting perceptions about the nature of technology and related educational, social, and political issues. While many teachers held an instrumental view of technology, some of them did acknowledge the social and political aspects of technology and were cautious about the possible mediating effects technology might have on the school culture. Among other issues, Ferneding's study suggests the complexity of teachers' conceptions of technology and education reform, conceptions that are framed in local context and culture and teachers' "personal practical knowledge."

Carroll and Eifler (2002) explored 41 teachers' perceptions about the nature of technology by means of the metaphorical language they used to describe technology and their experiences with it. The authors organized the teachers' notions of technology into the following categories: (1) an entity with capacities, needs, and appetites; (2) a tease; (3) a specific kind of butler; (4) a tool; (5) a power without form; and (6) a double-edged sword. In this study, the researchers understood that metaphors could structure human thought and action, but they did not show how the participating teachers' perceptions about technology and pedagogy were influenced by the metaphorical language they used to reason the relationships among technology, education, and society.

How does the current study compare to the previously mentioned research? Fleming's survey provides a general account of a large number of teachers' perspectives of technology; the current study involves in-depth interviews with a small number of teachers regarding their profound beliefs about technology, mathematics education, and society. Ferneding's study focuses on practicing teachers' perceptions about their schools' adoption of technology; the current study targets on preservice teachers in the particular field of mathematics education. In Carroll and Eifler's study, technology generally means computers (instrumental view); the current study has a broader definition of technology and discusses teachers' perceptions of

technology in epistemological, ontological, and cultural dimensions. Moreover, as mentioned earlier, there is a lack of empirical research on teachers' views of the nature of technology. Most studies focus on the application of technology. Unlike this dominant type of research, the current study sought to unveil the critical philosophical stance teachers may have toward the integration of technology in school curriculum. The author hoped to open a new window from which to look at how teachers conceptualize the role of technology in education.

Research Design and Data Analysis Procedure

The study took place mostly in the educational technology course the author taught in a comprehensive university in the Midwest of the United States. This one-credit-hour course was required for a teaching credential. The preservice teachers in the class were requested to write a philosophy of technology statement as part of their professional portfolios. This assignment was developed to understand how teachers defined technology and its relationship to (mathematics) education and society.

Participants

The participants were the 22 preservice secondary mathematics teachers in this course. Among them, 8 were male and 14 were female. They were between 20 and 27 years old. In their freshman and sophomore years, they were majors in mathematics, science, or engineering. During their junior and senior years, they were enrolled in the secondary mathematics education program. This study was conducted in the final year of their teacher education program, which included student teaching experience.

Data Collection

The data for the study came from three sources. First, the author/instructor kept classroom notes as he taught this course, including the events and discourses in the classroom. Second, all 22 teachers' statements on philosophy of technology were collected at the end of the course. Finally, one-on-one semi-structured interviews were conducted with five teachers who volunteered to elaborate their thoughts on thcir philosophy statements. The interviews typically lasted from 40 to 90 minutes. All interviews were audio-recorded and transcribed verbatim.

Data Analysis

I followed Strauss and Corbin's (1998) approach to grounded theory and my own inventions regarding the process of coding and the organization of the codes. I did not create a priori codes, but rather developed codes as I read and reread the participants' philosophy statements and interview transcripts. However, I had the instrumental and substantive theories in mind in the coding process. At the beginning, I coded the text sentence by sentence. I eventually examined a few sentences as a block, and I resumed micro-analysis as needed. I used a *concept* to summarize the data expressed in each sentence or block of text. Examples of such concepts include: "technology as a tool," "advantages of technology," and "augmentation of learning."

Next, I grouped similar concepts into *categories*. Categories are abstract notions, derived from data, that stand for phenomena, which depict the problems, issues, concerns, and matters that are important to those being studied (Strauss & Corbin, 1998). Examples of my categories include "neutrality of technology," "inevitability of technology," and "student need."

I also developed *analytic memos* focused on emerging categories. A category itself makes little sense unless it is linked to others. Thus, I related each major category to others. These memos had helped me with my analysis, interpretation, and directions for further data gathering.

Finally, to counter the researcher bias effect, I applied the strategy that Denzin (1989) calls "investigator triangulation." I asked two colleagues to review my data analysis and, based on their feedback, I was able to reduce such a risk.

Findings

The key findings are summarized in Figure 3, followed by the themes that emerged in the data analysis, which are organized along a dimension ranging from an instrumental view of technology to a substantive view. In order to provide a detailed account of the teachers' notions of technology, connections will be made to other constructs such as teachers' pedagogical beliefs and perceptions about student learning, as well as prcssing issues in education and society.

Defining Technology: Instrumental Perspectives

When asked to define technology, the participating teachers often referred to particular tools such as graphing calculators and the Internet. In this context, they generally subscribed to the instrumental theory of technology. In most cases, they thought that technology-as-tool was morally neutral and was a means to human ends. As teachers stated that

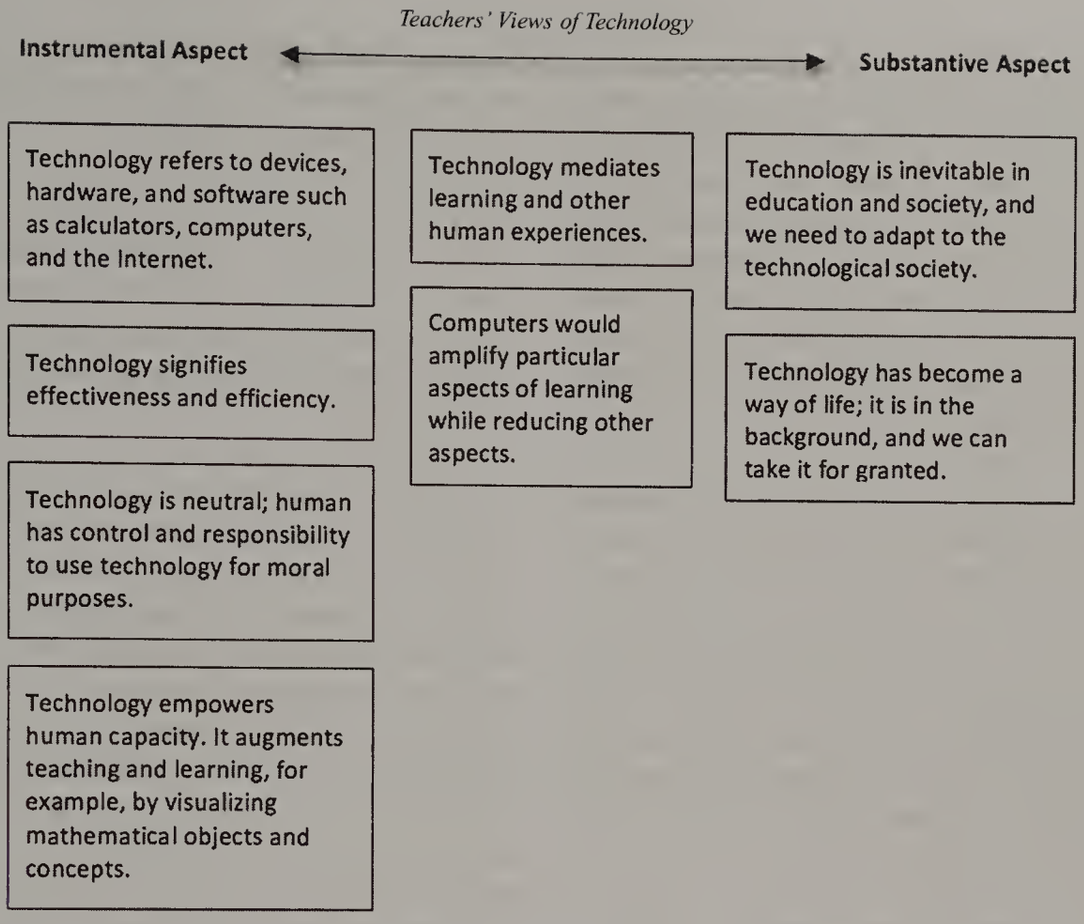
Teachers' Views of Technology
Instrumental Aspect
Substantive Aspect
Technology refers to devices, hardware, and software such as calculators, computers, and the Internet.
Technology signifies effectiveness and efficiency.
Technology is neutral; human has control and responsibility to use technology for moral purposes.
Technology empowers human capacity. It augments teaching and learning, for example, by visualizing mathematical objects and concepts.
Technology mediates learning and other human experiences.
Computers would amplify particular aspects of learning while reducing other aspects.
Technology is inevitable in education and society, and we need to adapt to the technological society.
Technology has become a way of life; it is in the background, and we can take it for granted.

Figure 3. Preservice mathematics teachers' perceptions of the nature of technology and its role in mathematics education and society.

"technology is a great tool to have in the classroom, but educators should enforce that technology is merely a tool . . . It is only as good as the person who is using it" and that, "technology is neutral and we can use it as we please . . . it's our personal choice."

A related notion to the neutrality of technology is that human beings have the control to use it for good or evil purposes. The participating teachers believed that it was up to teachers, students, and parents to use technology to enhance teaching and learning while at the same time avoiding the pitfalls of technology. Two examples the teachers gave were: (1) students should use graphing calculators to assist problem solving instead of using them as a crutch that inhibits basic skills; and (2) the Internet could provide students with useful information or expose them to violence, depending on how it was used. As one teacher put it, "technology is good in the class if used correctly, and it's good in society if used correctly." This view of technology suggests that when something is wrong, humans are to be blamed.

Technology as Empowerment

In addition to the neutrality of technology, the teachers spoke of empowerment of technology. In the particular field of mathematics education, tools such as graphing calculators, computer-based algebra systems, and Geometer's Sketchpad could augment students' learning of mathematics by performing complex calculations, showing connections among different representations, and visualizing mathematical concepts. In fact, visualization was commonly cited by these teachers as a salient advantage of electronic technology. For instance, a teacher thought that graphing calculators were "really cool for algebra students learning functions to *see* velocity over time, distance over time." Commenting on Geometer's Sketchpad, another teacher stated that "the main idea was for them [students] to visually *see* [italic added] what the Pythagorean Theorem was."

Indeed, visualizing mathematics and making learning and teaching "easier" were commonly heard in these teachers' discourses about the empowerment of technology. Furthermore, terms such as "easier," "better," and "faster" are related to the notion of *efficiency*, a key idea in these teachers' perceptions about the role of technology in education. "Technology is a quicker way to speed up things." "It lets us do a lot more in small amount of time."

Mediating Nature of Technology

The participating teachers had some understanding of the mediating nature of technology, an understanding that technology could influence what and how we experience learning and the world around us. For example, one teacher thought that computers have only two senses—input and output, while human beings have five senses. Thus, humans' use of computers would always result in some reduction in the experience. She stated that:

> In relying too heavily on technology, creative, emotional, and community aspects of the classroom experience and of mathematics are quelled. While a student may be able to individually enter numbers into his calculator and solve a problem, that same problem may have been able to be approached through group exploration, modeling, or discussion, resulting in a greater understanding of the actual and important mathematical workings behind the initial problem.

This teacher understood that, although computers allowed individual students to solve a problem based on input and output, the affective and socio-communicative domains of student learning were stifled. Thus, while technology can amplify certain aspects of learning, at the same time it decreases other aspects.

A few teachers commented on the role of electronic spreadsheets in mathematics education. Most of them appreciated the power of this technology for organizing data, generating graphs, and providing multiple representations. One teacher noted how Microsoft Excel could mediate learning because activities were framed in terms of the built-in functions of the technology. He stated that, "students' learning is oriented toward using variables, formulas, and graphs, which are the fundamental features of Excel." However, the teacher noted that the use of variables was not direct; it was through the use of cell coordinates on the Excel spreadsheet. For example, instead of using x and y, students had to use *D5* and *D6*. Apparently, this teacher understood the mediating nature of spreadsheet technology and its educational possibilities and constraints.

Inevitability of and Adaptation to Technology: Substantive Perspectives

According to most teachers in this study, one substantive aspect of technology was its *inevitability*. The following passage represents a common belief of participating teachers, a notion that technology and society are deeply intertwined:

> This world is becoming more and more technology dependent . . . There are so many things that are so technology driven that almost every single career, almost every single thing that you want to do in life later on, it involves some sort of technology.

Most teachers thought that technology was everywhere in the American society and that there was no escape from it. One teacher stated that "our modern world is changing constantly, and much of this change is due to the overwhelming influence of technology in our society. At times it seems that our entire lives are being controlled by electronic devices of all shapes and sizes." This passage suggests that technology might have taken over human lives, a worry expressed by many writers of science fictions and films such as *The Matrix*. However, the participating teachers did not believe that technology determines human thought and action, although they recognized that technology was transforming schools and society.

Most teachers in this study had some understanding of the substantive impact of technology on education and society, especially when reflecting on drawbacks of technology such as digital divide and environmental crises. Unlike substantive theorists who can be pessimistic about the "technological society" (where only God can save us), the teachers were optimistic about the way technology is leading the society into and the way it is used in education. In effect, they had developed very positive attitudes toward technology and believed that it is imperative to incorporate technology in their teaching to help students thrive in a technology-rich society. In particular, drawing on Charles Darwin's evolution theory on natural selection, a teacher repeatedly spoke of the need for students to learn about ICT to adapt to the American technological society. He stated:

> It's very essential to have technology somehow in the curriculum in schools because almost everything that they [students] can do in society is going to have some sort of technology in it. They might as well become familiar with it. Whether they realize it or not, later on in their lives, they're

> going to be working with technology, and it's good for them to have experience working with new things, even if it's not something they're going to use. The whole idea behind them learning to use new things, that concept is going to help them *adapt* [italic added].

This teacher might not recognize it, but his vision of helping students to adapt to a technology-based society is an example of substantive theorists' worry about how Western societies are largely organized and operated according to a technological order. This phenomenon can be seen through teachers' discourses about their responsibilities and students' needs. Many teachers in this study thought that it was their responsibility to equip students with technology skills for their future careers and lives in which technology is an essential part. In other words, students who are not "technologically literate" would be denied prestige in society.

Here, we see that a substantive view of technology, especially that technology is inevitably directing schooling and social life, is closely related to the notion of students' responsibilities in learning. In this junction, the discourse about *inevitability* of technology is associated with the discourse of pedagogical *necessity* and *student needs*. As a teacher put it, "I think technology is necessary to keep up with society competition . . . So technology is definitely necessary [for students] to make more money or to hold more powerful positions in society."

Discussion and Implications for Mathematics Teacher Education

There was an internal ambiguity in the participating preservice teachers' perceptions about the nature of technology. This ambiguity represents an uncertainty in their discourses, as well as an oscillating ambivalence in their beliefs, attitudes, and practices. Indeed, they experienced technological tools as things that they used; technology was seen as morally neutral in the sense that it awaits a human agent to animate it for a moral purpose. At the same time, they were aware of the inevitability and mediating nature of technology and its substantive impact on education and society. Moreover, the teachers, consciously or unconsciously, anthropomorphized technology and endowed it with a sort of autonomous agency as if it exercises power in society, a power that human beings need to utilize or contain.

While the preservice teachers had both views of technology and ambiguous beliefs about its application, their perceptions were imbalancedly geared toward the instrumental end in the instrumental-substantive spectrum. They also demonstrated an inclination toward a techno-centric mindset of educational computing (Ferneding, 2003; Kerr, 1996), and many teachers in this study held a naïve faith in the power of technology to improve education and human life. They were susceptible to a set of related propositions promoted by technology advocates: that technology will improve teaching and learning, that teachers and students need to use state-of-the-art technology to stay on top of global, economical competition, and that technology should find application in many disciplines and aspects of our lives.

This techno-centric ideology has a deep historical and philosophical root in the Cartesian view of human subjectivity and autonomy. In Cartesian epistemology, there is a split of human mind and the objective natural world. Human beings are considered to be rational individuals in search for universal scientific truth and technological means to control nature. Furthermore, Shutkin (1998) argues that the Cartesian world view is a defining element in Western culture. He posits that from the 17th century to the 19th century, "a social vision emerges ecclesiastical ideals of human progress with a faith in technological progress: Technology is to augment the capacities of the individual" (p. 220). Indeed, as I have shown in the previous sections, the teachers overwhelmingly believed that technology, mostly thought of as external to human minds, has a great power to augment students' mathematics ability.

According to Bowers (1988, 2000), the Cartesian notion of human subjectivity and the instrumental view of technology provide a theoretical foundation for the techno-centric mindset outlined previously, which is embedded in most educational policies and software. Software designers, educators, and policy-makers who subscribe to this techno-centric mindset tend to take the neutrality of technology for granted and are oblivious to the socio-cultural dimensions of educational computing and the substantive impact of technology.

Most teachers in the current study had this techno-centric mindset. Although some of them had some understanding of cultural and socio-political dimensions of technology and how it could mediate teaching and learning, in general, they tended to overlook or underestimate the substantive impact of technology in education and society. It is evident that while the

teachers were encouraged to reflect on pedagogical and socio-cultural issues associated with technology, most of them could not either name the issues or articulate their understanding. They did not have a linguistic and conceptual framework from which to examine thoroughly how technology influences human consciousness.

In *The Culture of Technology*, Pacey (1983) argues that many professionals are trained to use their knowledge selectively and to reason in a particular way. Doctors are oriented to curing disease, not to preventing it. Engineers tend to focus on technical aspects of the use of devices and are oblivious to human aspects (organizational and cultural dimensions) of their use. Pacey sees a problem that as professionals proceed through their education, they are inscribed by the specific rationality of their field and become more and more one-dimensional in their reasoning and problem solving. Pacey calls this phenomenon a *tunnel vision of technology*, which urges professionals to treat a complex and highly differentiated set of things as if they could all be organized in one sort of technological model.

This tunnel view of technology is seen in this study, which concerns the mathematics teaching profession. The participating teachers' visions of the educational use of technology were mostly confined within an instrumental and techno-centric framework. Similar to the engineers in Pacey's study (1983), these mathematics teachers were oriented toward narrow, technical aspects of the use of ICT in education. If Pacey was right, then any reform effort pertaining to integrating technology in education that fails to address organizational and cultural dimensions of the issues is due for disappointment.

It is my contention that our theorizing about technology and education should be able to do justice to the importance of both the instrumental and substantive theories of technology without falling into either pole. Teachers (and students) should understand that technology is not only a tool but also a socializing process. For research and practice, it is important that we investigate how teachers (and education stakeholders) can obtain a balance between instrumental and substantive views of technology. I will elaborate my contention in the following three points.

An In-depth Understanding of the Role of Technology in Mathematics Education

The role of technology in mathematics education in lights of the instrumental and substantive theories of technology is provided earlier. To recap, educators subscribing to the instrumental theory treat technology as an external and neutral entity that can augment the learner's cognitive ability. Substantive theorists focus on the intertwining relationship between technology and the learner who embodies technology in his or her learning of mathematics in a socially, culturally, and tool-mediated setting. The findings of the study reveal that most of the time, the participating teachers had the instrumental view of technology. Only in a few occasions did they reflect on the mediating nature of technology and its socio-cultural dimensions.

The participating teachers' understanding of the nature of technology was *correct* but not *true*. They were *correct* in that when students first use a new technological tool such as a graphing calculator or a dynamic geometry program, they have to familiarize themselves with the interface and learn how to use the device or software to perform mathematical tasks. At this early stage, technology tends to be external, and students constantly experience the presence of the technology as they endeavor to understand the appropriate keys and commands necessary for manipulating mathematical objects.

The participating teachers' understanding of technology was not *true* because they did not see a deeper level of the intertwining relationships among the learner, technology, and mathematics. There is a lack of evidence of the preservice teachers' understanding that technology-supported learning activities are constrained by technology structure and the socio-cultural conditions linked to the specific nature of the experience the technology enables. Thus, teachers can benefit from the substantive theory of technology and investigate the next stages of students' use of technology. Drawing from the work of Heidegger, Don Ihde (1979) posits that tools *withdraw* when they are fully embodied in the person's experience of the world. For example, when a writer immerses him/herself in writing, (s)he would totally focus on expressing his/her ideas. The computer or word processor "disappears" from the writer's consciousness. It implies that when students learn how to use a tool or software program, they gradually develop what Rivera (2005) called "instrumental schemes," or tool-mediated thoughts and actions, that enable them to focus on the mathematical tasks. In Rivera's (2007) empirical study on pre-calculus students' use of graphing calculators, at the final stage of the development of

instrumental schemes, students fully embodied and transformed the tool, and were able to engage in an abstract, theoretical investigation of mathematics. Rivera also noted that the technology-mediated classroom interactions were crucial for such higher-order learning to occur.

To put it in the instrumental-substantive framework, at the beginning, the students in Rivera's study (2007) had to rely on the graphing calculator as *external* help to develop their mathematical knowledge, which is an instrumental aspect of technology. Gradually, they developed the knowledge and skills to use the graphing calculator in mathematics investigation, and they experienced partial embodiment of the tool. Finally, the students were able to focus solely on the higher-level mathematical tasks, and when fully incorporated in the learning process, the tool became a *background* that immanently mediated the learning by providing the condition of possible structuring experience, which is indeed a substantive aspect of technology.

Therefore, an understanding of *both* instrumental and substantive theories of technology can help teachers become sensitive to instrumented activities and the trajectory of how students embody technology and how their learning experience is mediated by technology. Such an understanding, in turn, can help them effectively structure the mathematical tasks, small group or plenary interactions, and classroom discourses conducive to meaningful construction of mathematical knowledge. Indeed, Rivera (2005) argued that effective use of technology to enhance students' meaningful construction of mathematical knowledge calls for a shift from a cognitive, psychological perspective on the construction of mathematical knowledge to one that is also socially, culturally, and tool mediated. I will elaborate this point in the next two sections.

An Epistemological and Ontological Reflection on What It Means to Learn Mathematics

Confined in the instrumental view of technology in education, which is associated with the Cartesian and the traditional cognitive view of learning, the participating teachers were mostly oblivious to how technology could greatly mediate students' experience with mathematics and how they *make sense* of the learning process. Rivera (2005) aptly pointed out that, "when learners use tools to acquire knowledge without developing meaningful schemes, then the knowledge they produce may be superficial, and the operations they perform tend to be procedural" (p. 135). Endowed with a substantive view, teachers can see at a deeper level how technology immanently influences students' experience with mathematics. Rivera discussed three empirical studies and concluded that when students went through instrumentation process of dynamic geometry software, they could be engaged in a construction of mathematical knowledge and experience what it means to produce knowledge. As students embodied technology in a well-structured social context, they could become active agents in an epistemology of mathematical knowledge.

Such ownership or authorship of mathematical knowledge, in my opinion, is a powerful perspective on mathematics education. Many people, including teachers, are not thrilled in their schooling experience with mathematics because they do not feel that they own mathematical knowledge, which is thought as external to them. Frankenstein and Powell (1994) discussed the nature of mathematics and argued that traditionally mathematical knowledge is the privilege of an elite group and that many children are kept out of school mathematics. "Prevailing pedagogical practices have prevented and alienated many students, disproportionately people of color and women, from engaging in mathematics" (p. 80). While technology is not the only viable means to engage students, it can assist them to approach mathematics in a meaningful way. This vision of mathematics education calls for an ontological investigation of the relationship between the nature of technology and the subjectivity of the learner. In the present study, the instrumental view of technology can reinforce teachers' and students' detached view of mathematics; that is, seeing mathematics as external to their lived worlds. For them, it is hard to find meanings and purposes in mathematics. On the other hand, the substantive theory of technology deals with the nature of being and thus provides a powerful framework from which to look at how teachers and students conceptualize the interaction among human subjectivity, the nature of technology, and the nature of mathematics learning.

A Critical Stance Toward Educational Technology Research, Practice, and Policy

While not a panacea for educational "problems," technology can have a great potential to transform schools, in particular, allowing all students to access powerful mathematical ideas (NCTM, 2000). This potential was naively conceived (Cuban, 1986, 2001), and teachers and policy-makers can be susceptible to technology advocates' propagandas filled with

political and commercial interests (Robertson, 2003). Recently, educational researchers and teacher educators have gradually enhanced their understanding of the nature of technology and how it mediates teaching, learning, curriculum, and school culture. For example, Koehler and Mishra (2008) stated that "technologies are neither neutral nor unbiased; rather, particular technologies have their own propensities, biases, and inherent attributes that make them more suitable for certain tasks than others" (p. 5). Recognizing that technology is non-neutral, Freidhoff (2008) discussed the affordances and constraints of technology and provided strategies for evaluating and selecting technological tools for meeting particular pedagogical purposes.

In addition, an in-depth analysis of the inherent characteristics of technology is provided by Bowers (1998, 2000), who unpacked the cultural assumptions, values, and patterns of thinking embedded in educational computing. He argued that current educational software reinforces linear way of thinking, assumes that data and information are the basis of thinking, and leads to ecologically destructive patterns of culture. At the same time, implicit, contextual knowledge is diminished by computer-mediated learning. Thus, he urged educators to recognize the mediating nature of technology and to counteract the trend that students are been socialized to technical way of thinking and living. The previously mentioned three pieces of literature represent an inquiry into the role of technology in education, which helps educators increase their understanding of the complexity of integrating technology in education.

The current study shows that while the educational technology and teacher education communities have broadened their understanding of the nature of technology and what it takes for an organizational change (Ertmer, 2005), preservice teachers have yet given adequate opportunities to enhance their understanding of the characteristics of technology. Indeed, the findings of the study suggest that the participating teachers had some understanding of the mediating nature of technology and its substantive impact on education and society. While their understanding was subtle and ambiguous, it can be made more explicit and clearer. Flick and Lederman (2003) posit that an exploration of what constitutes technology and a reflection on how it affects our lives should be part of school curriculum. Similarly, teacher education institutions and professional development programs should explicitly engage teachers in a conversation about the nature of technology and how we can break a tunnel view of technology use in education. As we often say, we teach children, not mathematics. In addition to using appropriate technology in mathematics classrooms, can we not consider technology's epistemological, pedagogical, ontological, organizational, and cultural implications?

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"Mathematicians Would Say It This Way": An Investigation of Teachers' Framings of Mathematicians

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Although popular media often provides negative images of mathematicians, we contend that mathematics classroom practices can also contribute to students' images of mathematicians. In this study, we examined eight mathematics teachers' framings of mathematicians in their classrooms. Here, we analyze classroom observations to explore some of the characteristics of the teachers' framings of mathematicians in their classrooms. The findings suggest that there may be a relationship between a teachers' mathematics background and his/her references to mathematicians. We also argue that teachers need to be reflective about how they represent mathematicians to their students, and that preservice teachers should explore their beliefs about what mathematicians actually do.

When reading popular comic strips, we often find manifested in the humor a portrayal of mathematically gifted students and mathematicians as geeks, nerds, social misfits, and even fools. Negative images of mathematicians can also be found in literature and in the movies (Furinghetti, 1993). While we agree that the representations found in popular culture influence students' beliefs about mathematicians, we contend that experiences in mathematics classrooms can also contribute to students' images of mathematicians.

Providing no empirical evidence, Picker and Berry (2000) claimed that it was "very rare" to "hear the word mathematician used during the lesson" and that "it is very unusual to hear pupils addressed . . . as mathematicians" (p. 90). Our decision to investigate teachers' framings of mathematicians came after reading this article and noticing that the secondary teachers with whom we work *did* talk about mathematicians. By "framings," we mean the words teachers explicitly say about mathematicians and what they do. We have selected the term "framings" because our meaning is more like Barnes' (1992) discussion of the word "frames" than other word choices like "description," which is typically used in a more "objective" way. The word "frames" recognizes that teachers bring knowledge of the context in which they are working as well as implicit and explicit systems of beliefs, knowledge, and values to the settings in which they work. Teachers' frames are value-laden and dynamic and typically result in intentional and unintentional practices.

Both students and teachers are affected by the views of mathematicians and mathematics that are portrayed in society and in the media, and the image generally portrayed is not a good one (Picker & Berry, 2001). The majority of students' mathematical experiences,[1] however, occur in the classroom. Therefore, the nature of the students' classroom experiences becomes absolutely critical in forming their images of mathematics and mathematicians (Schoenfeld, 1985).

Over the 2005–2006 school year, we collected classroom observation data in eight different mathematics classrooms and observed different framings of mathematicians. In our investigation of 148 classroom lesson transcripts, we found that 14 of the lessons contained the word *mathematician*. This finding confirms Picker and Berry's (2001) claim that references to mathematicians are fairly rare. We also noticed, however, that the framings of mathematicians were interesting and not necessarily positive ones. In this paper, we describe the framings of mathematicians that were communicated explicitly to students by their mathematics teachers. In the final section of the paper, we return to literature on images of mathematicians and on students' beliefs in order to raise issues about how these framings might contribute to students' images of mathematicians. We also raise issues

about the teachers' past experiences and how those experiences might be shaping the ways in which they frame mathematicians.

Related Studies

The sparse literature on students' images of mathematicians has drawn on research methodology used in science education (e.g., see Chambers, 1983; Huber & Burton, 1995; Krause, 1977). Drawing on this work, in mathematics education, Rock and Shaw (2000) examined students' responses about what mathematicians do, what types of problems they solve, and what tools they use. They found that most students believed that mathematicians do "hard problems that other people don't know" (p. 552). In another study, Picker and Berry (2000) asked students to explain their drawings of mathematicians and to identify a situation where they might need to hire a mathematician. Picker and Berry identified the following themes in the students' drawings: *mathematics as coercion*; *the foolish mathematician*; *the overwrought mathematician*; *the mathematician who can't teach*; *disparagement of mathematicians*; *the Einstein effect*; and *the mathematician with special powers* (pp. 74–75). These authors also found that students primarily thought of mathematicians as males who would be hired to teach mathematics classes.

Despite the fact that mathematicians do not view their work with such negativity (see, e.g., Burton, 1999b; Henrion, 1997), some of the findings related to students' representations of mathematicians are not surprising when we look to research on students' beliefs. For example, the students in Schoenfeld's (1985, 1988) studies believed that formal mathematics has little or nothing to do with real thinking or problem solving, that mathematics problems are always solved in less than 10 minutes if they are solved at all, and that only geniuses are capable of discovering or creating mathematics. A consequence of this last belief, according to Schoenfeld, was that students tended to accept procedures at face value and did not try to understand why they worked. These procedures, students believed, were passed on "from above." If students have experiences in school that lead them to believe that mathematics has little or nothing to do with real thinking or problem solving, then we can understand why students would construct drawings of mathematicians who are foolish or overwrought. Thus, it is important for teachers to consider the implicit and explicit messages that they are communicating to their students. In the final section of the paper, we provide additional literature that is relevant in order to highlight why the framings of mathematicians we describe matter to the teaching and learning of mathematics, as well as to the education of prospective and practicing teachers.

Our goal in this study is to examine the framings of mathematicians that teachers explicitly communicated to their students. More specifically, this study examined mathematics teachers' framings of mathematicians. This study was guided by the following question: What are some of the characteristics of the teachers' framings of mathematicians in their classrooms?

Methods

Participants

The data for this study come from a larger NSF-funded study (Beth Herbel-Eisenmann, PI) which is focused on how doing action research on mathematics classroom discourse might impact teachers' professed beliefs and classroom practices over time. Eight teachers from seven schools in a Midwestern state in the United States participated in this study. The teachers were purposefully selected to diversify gender, context of teaching situation, years of teaching experience, and so on. Three of the teachers were elementary certified and five of them were secondary certified. Further information about the broader project can be found in Herbel-Eisenmann and Cirillo (2009) and Herbel-Eisenmann, Drake, and Cirillo (2009).

Later in the article, we highlight one tenth-grade geometry teacher, Matt,[2] who became the focus of additional investigation for this article. Here, we provide information about Matt in order to help the reader better understand our interpretations of his framings of mathematicians. Before Matt graduated from high school, he completed Calculus III at a university. His Bachelors degree is in mathematics, and his Masters degree is in Mathematics Education. He also completed 15 credits of philosophy electives as a part of his university coursework.

Data Collection

Although more extensive data were collected for the broader project, we only describe the specific data sources we used for this analysis, including classroom observations, interviews, and written journals. All eight teachers were observed teaching in their classrooms throughout the 2005–2006 school year. We observed a week at a time for four full weeks

approximately every other month of the school year, resulting in 148 observations. During the 2006–2007 school year, Cirillo also observed in Matt's classroom as part of her dissertation work (see Cirillo, 2008). Because Matt most frequently discussed mathematicians during his lessons, we also analyzed these 13 additional classroom observations. All classroom observations were video- and audio-taped. Each lesson was transcribed using Transana (Fassnacht & Woods, 2005).

All teachers kept written journals for the larger study in order to record impromptu reflections as well as to respond to questions that we asked them. Relevant to this study were the responses to the following questions: (1) What is mathematics?; (2) What does a mathematician do?; and (3) Are you a mathematician? Teachers were asked to respond to these questions after we noticed that many of them talked about mathematicians in their classrooms.

Data Analysis

A search engine was used to find all instances of the word *mathematician* in the classroom transcripts. Transcript excerpts that included the word *mathematician* were then compiled into one document, allowing us to look across the examples. Focusing on this subset of transcripts, we independently used open coding (Esterberg, 2002) to identify themes and categories in the text. After identifying key recurring themes, we discussed them and reached consensus on a set of themes. In the next section, we describe these themes and illustrate them by using typical examples from the classroom observation data.

Although the primary data source for this study was the classroom observations, the journal entries and interview data helped us to better understand the participants' perspectives on what mathematicians do and who might be considered a mathematician. We use this data to ground the framings we describe. We begin with a general description of how the teachers used the word *mathematician* in their classrooms and some of the information we gathered from their journals. We then describe and illustrate the specific themes we identified in the analysis of the classroom observations.

Results and Preliminary Discussion

General Description of Teachers' Framings of Mathematicians

During the 2005–2006 school year, we found that all of the references to mathematicians were made by teachers (not students). In some passages of the classroom transcripts, the teachers used the word *mathematician* multiple times, resulting in a total of 24 instances occurring in 14 lessons. All but one of these instances were found in classrooms where the teachers were certified to teach secondary rather than elementary mathematics.[3] Given the responses we received to the journal prompt, "Are you a mathematician?" we were not surprised by this finding.

All of the secondary-certified teachers indicated that, based on their definition of mathematician (which they wrote for a previous question), some of their ways of doing and thinking about mathematics were similar to the ways a mathematician does and thinks about mathematics. For example, Jackie, an eighth grade teacher, said, "I do not see myself as a mathematician . . . however, I do see myself as doing mathematics" (Journal, 6/21/06). The positioning that was most closely aligned with being a mathematician came from Matt, who wrote, "Although I tell my students all the time that I am not a mathematician, I would [by my definition of mathematician] probably be classified as an armchair or amateur mathematician" (Journal, 6/21/06). Matt was also the teacher who referred to mathematicians every week that we observed him. We further discuss Matt's positioning with respect to his mathematical experiences in the Discussion and Implications section.

In contrast, all three of the teachers who were certified as elementary school teachers gave a response that indicated that they did not see themselves as mathematicians at all. For example, Tonya, an elementary certified teacher, wrote:

> I honestly have no idea what a mathematician does . . . I do not see myself as a mathematician because the word implies to me very complex problem solving. I do not feel I have that ability or level of understanding of math to solve those types of problems. (Tonya, Journal, 6/21/06)

Tonya's statement that she has "no idea what a mathematician does" helps us understand why we did not hear her mention mathematicians during her lessons. The responses written by the other elementary school certified teachers indicated similar positionings as this example. Although these teachers did not feel they really knew what mathematicians did, they were pretty sure that the mathematical processes in which mathematicians engaged were more complex than they were capable of doing.

Themes in the Classroom Observations

We identified five themes related to teachers' uses of the word mathematician. These themes include: efficiency; historical development of mathematics; mathematical convention; teachers referring to students as mathematicians; and mathematicians in conflict with others. Although multiple examples exist for each theme, we provide an illustrative example that characterizes each of the themes below. Within these examples, we highlight how students are subtly positioned through the teachers' language practices.

Efficiency. There were four examples where teachers spoke about mathematicians with respect to saving time. Most of these examples came from Matt's classroom. In some examples, Matt cited laziness as the reason for mathematicians' desire to save time. The following is an example from a lesson on geometric translations on the coordinate plane:

> Matt: What if I want to move that shape? Now, how many directions am I going to have to give you? A lot, right? Too many. **Mathematicians** are lazy. Okay? We're lazy bums. We don't want to give you a direction, a different direction for every coordinate. *It takes up too much of our time. It's a waste of time . . .* [4] So if I move one point to one point, everything else should fall in place? Right? So now I've reduced 15 sets of directions to one direction. Right? What if I want to be even lazier than this? Think about maximum laziness. This is too much to write. What could I tell you in order to know how to move this entire shape from one place to another? I don't even want to write this much. How could I describe this move?
>
> Student: [inaudible]
>
> Matt: . . . Five down, three left. Okay. You're a **mathematician** if you do this enough, what are you going to stop telling me?
>
> Student: Is it like a slope of a line? [inaudible]
>
> Matt: Slope of a line. Right. But *over time*, we're **mathematicians**, these words are going to become redundant. (Matt, Obs., 1/23/06)

In this example, Matt attempted to convince his students that it made sense to have a way to represent the translation of the multiple points of a shape (i.e., an irregular 15-sided polygon) by using a single notation (i.e., $T_{-3,-5}$) rather than a longer, wordy description. Writing a direction for each point, Matt said, "takes up too much of our time" and is a "waste of time." After saying that mathematicians were lazy, however, Matt then positioned himself as a mathematician, saying, "*We're* lazy bums. *We* don't want to give *you* . . . a different direction for every point." As Pimm (1987) has pointed out, pronouns serve the purpose of defining membership. That is, "we" could refer to the teacher only, the teacher and the broader community of mathematicians, the teacher and the students in his class, and so forth. Matt's use of the word "we" makes ambiguous who should be included in the group of people to whom he refers. It becomes clear, however, that his students are not being positioned as part of this group when he referred to them as "you" shortly thereafter. Later, he said, "You're a mathematician if you do this enough . . . " In other words, Matt's students could be mathematicians, but only "if" they spent more time at this practice. Thus time also played a role in whether or not students might eventually become mathematicians.

Historical development of mathematics. The following example was related to time but focused more on *the historical development* of mathematics over time. In this seventh grade classroom, Audrey set up an exploration of the relationship between the circumference and the diameter of a circle by saying:

> What we're going to try to do today is discover something that **mathematicians** discovered a *long, long time ago. Way, way before my time.* We're going to try to discover how to predict the circumference of a circle. And we're going to need to take two measurements to be able figure it out. (Audrey, Obs., 2/2/06)

In this case, Audrey was, in some ways, telling the students that they were going to do the same work that past mathematicians had already done. In the Platonic sense, students were being encouraged to discover a "necessary" (as opposed to "arbitrary" [Hewitt, 1999]) result in mathematics. In this way, the students might see their work as similar to the work of mathematicians. Because students were doing the same thing that mathematicians did millennia ago, an alternative interpretation could be that students might see mathematics as a static, unchanging set of rules. What they were doing was not cutting edge or contemporary,

which is the nature of school mathematics. That is, any mathematics that is "discovered" by students in the classroom was actually discovered (or invented, depending on your philosophical viewpoint) millennia or centuries before. Some of the examples related to historical time and efficiency also referenced mathematical convention. The examples in the following section, however, are more explicitly about the mathematical conventions used in mathematics.

Mathematical Convention. There were four instances in which the teachers talked about mathematicians in the context of mathematical convention. The example given below came from an eighth-grade classroom where the teacher, Penny, was discussing whether an algebraic term should be written as $a4$ or $4a$:

> I'm going to tell you this: **mathematicians** would say it this way [points to *4a*]. *Although it means the same thing, your math book or* ***mathematicians*** *will say it this way.* So whenever you see a variable times a number, it is okay to flip flop them because multiplication is commutative. So it's okay to switch it, right? And **mathematicians** write that [points to $4a$]. So what are we writing for our answer on three? (Penny, Obs., 9/29/05)

In this case, Penny cited the textbook and mathematicians as reasons for using the mathematical convention of writing the coefficient before the variable. When she said "math book *or* mathematicians," Penny may have sent the message that these two resources were equal authorities or, alternatively, that mathematicians were involved in authoring the mathematics textbook. When she said, "I'm going to tell you this . . . ," Penny positioned herself as a person who had access to what mathematicians do and value rather than positioning herself as a mathematician. She also provided the mathematical justification "that multiplication is commutative" as the reason that *a4* and *4a* were equivalent. In this example, although Penny did not put herself or her students in opposition to mathematicians, she also did not explicitly position students as mathematicians. In some classroom observations, however, teachers did explicitly position their students as mathematicians.

Positioning Students as Mathematicians. In two classrooms not yet mentioned, the teachers positioned students as mathematicians. Lisa, an eighth grade teacher who worked in a school with students who were achieving well above grade level, positioned her students as mathematicians more often than other teachers in this study. In all of her examples, Lisa spoke about choice of solution strategies when there was more than one way to solve a problem, or choice in her students' representations of their answers. These references positioned her students as mathematicians. In this example, Lisa positioned her students as mathematicians when she explained that students could either express the x-intercepts of a parabola as ordered pairs or they could simply list the x-intercepts:

> So we could say the x-intercepts are those two numbers, or we could say that the points, x is this, y is this, and x is this, y is this, are points on the graph. *And I don't care. I mean as long as we know that those are* x*-intercepts, that's fine. Or as ordered pairs.* **Mathematicians'** choice. (Lisa, Obs., 11/17/05)

In all of her instances, Lisa referred to students as mathematicians when she said that the way that students presented their work on paper was "mathematicians' choice" (or "mathematicians' preference"), using "mathematician" and "we" (or "you") synonymously. Rather than Lisa strictly mandating some things for which there were options (e.g., specific procedures or notation), the students were given the freedom to make such decisions.

Another example of a teacher positioning students as mathematicians occurred in a different eighth grade classroom. In a baseball example about the distance from homc plate to second base, Jeremy proposed a problem in which someone decided to make up his own rules and he was going to run straight from home plate to second base. He told students:

> It's 90 feet in between home plate and first base. Between first base and second base is 90 feet. Bctween second base and third base is 90 feet. Between third base and home plate is 90 feet. The question for *you* ***mathematicians*** is how far is it from home plate to second base? (Jeremy, Obs., 9/29/05)

In both of the examples presented in this section, students were positioned as part of the community of mathematicians. In Jeremy's classroom, however, the mathematical situation was not a "real" problem (i.e., a player would be more likely to throw the ball from home plate to second base than to run from those positions), and it was not the kind of a problem with

which mathematicians would be likely to concern themselves.

Mathematicians in Conflict With Others. All examples of the fifth theme appeared only in Matt's classroom. In the earlier example from Matt's classroom (in the *Efficiency* section), we pointed out that he used the pronoun "we" when he spoke about mathematicians, framing himself as part of the community of mathematicians. It is interesting that in most examples about efficiency, Matt tended to use mathematicians and "we" synonymously. In other instances, however, Matt seemed to disagree with mathematicians or the textbook and positioned mathematicians in contrast to others.

Matt sometimes positioned mathematicians in conflict with others, including: logicians, textbook authors, and "real people." For example, after teaching students how to write the inverse, converse, and contrapositive, Matt spoke about the use of the tilde symbol in logic. When Matt presented the symbolic notation for writing these statements, he asked students what symbol would make sense to use. Some students suggested they use the negative sign (–) rather than the tilde symbol (~). Matt responded:

> Have I given you my mathematics-is-the-oldest-continuing-discipline spiel yet? No, I haven't spieled that in here? Mathematics is the oldest continuing discipline. So therefore things that are simple in other disciplines, **mathematicians** have had way too long to think about and come up with different terminology, okay. So then they end up with really weird symbols . . . Unfortunately, this particular branch of mathematics the *people in logic have started to try to take it over*, okay? So the *logical coup* of about 700 years ago means that we now use this other random symbol, which has no place in mathematics that unfortunately our book has *succumbed to the whim* of the logicians . . . *If it were up to me*, we'd just use a minus sign because that makes more sense but, the logicians—there's this *ongoing war* in mathematics and logic. The **mathematicians** say math is real, logic is based on mathematics. The logicians say, logic is real, math is based on logic. And this is *an ongoing battle—an intellectual war of kinds*. (Matt, Obs., 9/26/05)

In this rather lengthy exposition, Matt juxtaposed mathematicians with logicians and distinguished between the symbolism used by logicians and mathematicians as well as the "ongoing war" related to which symbols should be used to represent mathematical ideas. He pointed out his opinion about the "random symbol," which he believed had "no place in mathematics." In fact, he used the word "they" to remove himself from this decision to adopt "really weird symbols" and expressed his dissatisfaction with how the textbook "has succumbed to the whim of the logicians." In this framing, the logicians were positioned as powerful—powerful enough to have determined something that became convention in mathematics. The way in which Matt told this story positioned him as being knowledgeable about these historical and intellectual "wars," but also positioned the decision-making power of the discipline as being bigger than his own.

The final point we would like to make from this example is that Matt was the only teacher who we observed outwardly disagree with his textbook. In this example, he pointed out that the "book has succumbed to the whim of logicians." There were other instances like this in Matt's classroom where he told students about mathematicians and their preferences and then used these stories to disagree with something in this textbook. Matt positioned himself as someone who had the authority to disagree with the textbook. His authority was further substantiated when he aligned himself with mathematicians in disagreements over topics included in the textbook (e.g., measuring angles). This type of critique of the textbook was not the norm in our data set. More often, we saw teachers use the textbook to reinforce mathematical convention and notation.

Finally, Matt juxtaposed mathematicians and "real people" when he spoke about the reflexive property:

> The reflexive property says that a number is equal to itself, okay? It seems too simple to have as a property, but this is—you know about the *difference between* ***mathematicians*** *and real people*, right? *Most real people don't need to try to write a property that says a thing is equal to itself*, right? Right? My pen is equal to my pen. *That seems dumb*, okay, but that's a property. (Matt, Obs., 9/27/05)

In this example, Matt pointed out that defining things that seemed obvious was a difference between "mathematicians" and "real people" and that this kind of

defining "seem[ed] dumb." This statement positions mathematicians as being separate from "real people" and potentially positions the students as not being mathematicians because most students probably think of themselves as "real people."

Discussion and Implications

In the previous section, we described the major themes that emerged from teachers' framings of mathematicians. From these findings, there are at least two potential relationships that need to be discussed: (1) the teachers' framings in relation to the literature on students' conceptions of mathematicians and mathematics; and (2) the teachers' framings in relation to their past experiences. These two points are important because they highlight the fact that students' conceptions of mathematics and mathematicians reported in the literature can also be seen in the framings we described. Furthermore, we argue, that the teachers' framings are related to some of the experiences they have had with mathematics and with other previous experiences. After we discuss each of these points, we address the implications this work has for mathematics teaching and teacher education.

Teachers' Framings and Students' Conceptions

Students' images of mathematicians, as reported in previous literature, can be found in some of the ways that mathematicians are framed in the classroom practices described here. Some of the ways that the teachers in this study referenced mathematicians with respect to efficiency could lead students to believe that to be a mathematician, one must create shorthand notation in order to save time. This framing can be seen in Schoenfeld's (1988) finding that students believed that problems should always be solved in less than ten minutes if they are solved at all. It may also relate to Picker and Berry's (2000) discussion of mathematicians having special powers in that the powers bestowed upon them allow mathematicians to make up symbols and name properties in order to communicate dense mathematical meaning.

In Matt's articulation of efficiency, what was highlighted in his use of "lazy" could be interpreted as a lack of persistence rather than the fact that writing something more concisely was typical mathematical convention. When efficiency was referred to in this way, we wondered whether this was an appeal to something the teachers thought students might value in their own mathematical work. That is, working on mathematics should not take a long time to do. This message may have appealed to students, but it may also have contradicted the message that there is sometimes value in prolonged mathematical exploration.

In addition, the framing of mathematicians as lazy does not capture the value that mathematicians place on the efficiency of notation and symbols. Mathematical symbolism is generally accorded the highest status by mathematicians because it is the semiotic through which the solutions to problems are derived (O'Halloran, 2000). Mathematical symbols are primarily used to designate with precision and clarity and to abbreviate (Davis & Hersh, 1983). Furthermore, some of the framings by the teachers were more about the "arbitrary," rather than the "necessary" aspects of mathematics curriculum (Hewitt, 1999). For example, the use of the tilde symbol and the symbolic notation used to represent translations are arbitrary notations that allow the user to concentrate on more advanced aspects of the problem. In fact, "without the process of abbreviation, mathematical discourse is hardly possible" (Davis & Hersh, p. 124). The emphasis on the arbitrary, rather than the necessary, may reinforce the belief (noted by Schoenfeld (1988)) that formal mathematics has little or nothing to do with real thinking or problem solving.

The focus on the historical development of mathematics left us wondering whether students might see the work of mathematicians as being applicable to present situations or only to situations from the past. Although this kind of framing can help students see mathematics as a human response to problems encountered, it may not allow them to see that it is also applicable to current issues. References to only historical time and not current investigations could contribute to students' lack of awareness about when they might need to hire a mathematician (Picker & Berry, 2000).

Matt's juxtaposition of mathematicians and "real people," may contribute to students' images of mathematicians as being more like Einstein, as reported by Picker and Berry (2000). Alternatively, it may construct mathematicians as having some special talents that "real" people do not have and, therefore, the average person cannot do mathematics. Furthermore, it might perpetuate the perspective that mathematicians are "abnormal," which may not be an appealing attribute to students. Because students are likely to see themselves as "normal" (rather than exceptionally gifted or mathematically talented), we question

whether or not the students in Matt's classroom would be influenced by these framings in ways that would deter them from considering a career in mathematics.

The view that people who are good at mathematics are not "normal" was echoed in the data of another recent study on students' beliefs about who is good at mathematics (Morge, 2005). The portrayal of the mathematically gifted as not "normal" is consistent with many of the framings of mathematicians in the media. Finally, the type of conflict-oriented framings Matt used when juxtaposing mathematicians with logicians also made us wonder whether this kind of representation might contribute to students' perceptions of "math as coercion" that appeared in students' drawings of mathematicians (see, e.g., Picker & Berry, 2000).

We found other evidence of the exclusive nature of mathematics in the teachers' use of pronouns. In the teachers' framings of mathematicians, only 3 of the 24 framings included students as part of the group of people who could be mathematicians. There were three instances of the theme *positioning students as mathematicians* (e.g., "The question for you mathematicians is . . . "). In particular, the use of "mathematician's choice" may counter the commonly held belief that there is only one correct way to solve a problem. It also provides a framing of empowerment for students to make decisions about mathematical processes. This was the only framing that we saw that might effectively work against some of the beliefs reported in the literature.

If we are to better understand students' experiences with school mathematics, it is critical that we understand a central factor in their experience: the mathematics teachers with whom they interact every day (Philipp, 2007). In order to gain a better understanding of the role that teachers' images of mathematicians play in their classroom practices, much more needs to be learned about teachers' images of mathematicians, their beliefs about mathematics, and how those images and beliefs relate to their portrayals in their instructional practices. Future research could include interviews with teachers at various levels to determine the kinds of images of mathematicians that teachers of mathematics are bringing to their classrooms.

As noted by Picker and Berry (2000), teachers seem largely unaware of their students' lack of knowledge about mathematicians and the role that they, themselves, play in shaping or changing their views. While we cannot control popular culture portrayals, we speculate that teachers and teacher educators could be best positioned to counter the messages sent by these other sources if they more consciously attended to their own beliefs about and framings of mathematicians.

Teachers' Framings and Their Past Experiences

This study highlights the importance of teachers' beliefs about mathematicians and the work that they do. Teachers' interactions with their undergraduate mathematics professors will likely influence their portrayal of mathematicians to their students. We find it particularly significant that neither of the two elementary certified teachers (who took the least mathematics credits) mentioned mathematicians to their students during our observations. Teachers who come from elementary preparation programs probably have fewer images of what mathematicians do and may never take a course from or interact with mathematicians in their programs. At institutions in the United States where research is primary to faculty's workload, elementary mathematics courses are often taught by graduate teaching assistants and not by mathematicians.

Another plausible explanation could be that the experiences elementary preservice teachers have are not positive ones. In our own experiences of teaching in mathematics departments at universities, we have heard the mathematicians with whom we work express only frustration or disdain for the students in the content courses for elementary teachers. It is possible that these negative feelings impact the ways in which they interact with prospective elementary teachers, contributing to elementary teachers' lack of confidence in their mathematical knowledge. This kind of experience would position elementary teachers in such a way that they do not feel as if they should say anything about mathematicians and what they do.

In contrast, one might think that secondary teachers who were strong mathematics students and who worked alongside mathematicians would have positive images of mathematicians. Matt's framings, however, illustrate that this is not necessarily true. Although Matt seemed to have the best understanding of mathematics and had the most experience interacting with mathematicians in his high school and collegiate experiences, his framings of mathematicians to his students seemed to portray mathematicians as people who were not "normal" or "common." In an interview, Matt said that mathematicians were "too far gone to really try to

relate to common people." Future research should include studies that seek to document how often mathematicians are actually discussed in classrooms and how the work of mathematicians is framed when they are discussed.

A closer look into the private world of working mathematicians, however, actually reveals a more social existence than the public image suggests (Henrion, 1997). In fact, "community operates at all stages of a mathematician's development: initial motivation, establishing a mathematical identity, getting a job, continued development, promotion, and recognition" (Henrion, p. 9). Similarly, Burton's research (1999a, 2005) dispels the myth that the work of mathematicians is primarily individualistic, but rather, has shifted to a predominantly collaborative/cooperative endeavor. Her work also addressed the myth that mathematicians are born rather than made. Most of the mathematicians in Burton's (2005) study commented on the critical role played by a teacher in directing them toward a career in mathematics.

In addition to the images portrayed by the media, by providing students with over 1,000 hours of seat time in mathematics classrooms throughout their K-12 experience, teachers and the tasks that they engage their students with are major contributors to the formation of individuals' images of mathematics and mathematicians. To counteract these images, professional development activities must provide in-service and preservice teachers with opportunities to make sense of the many discrepancies between current reform recommendations and their own classroom experiences as students and teachers (Lloyd, 1999). Teachers' awareness and understanding of their own experiences with school mathematics are necessary before meaningful and substantial changes in their behaviors are likely to occur (Chapman, 1999). It is not enough to teach preservice and in-service teachers effective pedagogy and content knowledge without including an examination of broader ideological issues (Cotti & Schiro, 2004), in this case, pervasive beliefs about mathematicians, what they do, and how their work is related to school mathematics.

As teacher educators, we need to better understand the images and beliefs of teachers (and students) so that instruction can address these (Drake, 2006). As with the work done in science education, the results of this study indicate that more work needs to be done to promote positive images of mathematicians. Additionally, consideration should be given to the possibility that classroom practices might also contribute to mathematics' unfortunate "image problem" (Malkevitch, 1989).

It is promising that some research has indicated that students' and preservice teachers' images and beliefs about mathematicians can be altered through interventions such as: meeting and interacting with working mathematicians (Picker & Berry, 2002) or having students explore their own images of mathematicians through various classroom activities (Mewborn & Cross, 2007; Morge, 2007). For example, Mewborn and Cross (2007) helped preservice teachers raise awareness of their beliefs about mathematicians by having them participate in the "draw a mathematician" task. In Picker and Berry's (2002) study, a panel of diverse mathematicians was asked to speak to middle school students about their work and some other interests that they had in their lives (e.g., music, surfing, and dancing). These panelists described mathematics as a language and a science of patterns. The panel "led many students to bridge the gulf they had originally felt between themselves and mathematicians" (Picker & Berry, p. 55). If our goal is to encourage more students to continue their study of mathematics, then we must begin by addressing their teachers' beliefs and knowledge about the work of mathematicians.

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[1] Although people use mathematics in their everyday life, they do not always identify those uses as "mathematical." School is one of the only contexts in which people engage in an activity that has been named "mathematics."

[2] To preserve anonymity, all teachers are referred to by pseudonyms.

[3] One of the elementary certified teachers has a Masters degree in middle grade mathematics. She was the exception to this statement.

[4] Throughout the examples, we use italics to note the words most related to the focal theme being discussed.

PROBLEMS section

Ted Eisenberg, *Section Editor*

This section of the Journal offers readers an opportunity to exchange interesting mathematical problems and solutions. Please send them to Ted Eisenberg, Department of Mathematics, Ben-Gurion University, Beer-Sheva, Israel or fax to: 972-86-477-648. Questions concerning proposals and/or solutions can be sent e-mail to eisenbt@013.net. Solutions to previously stated problems can be seen at http://ssmj.tamu.edu.

Solutions to the problems stated in this issue should be posted before April 15, 2011

• **5146:** *Proposed by Kenneth Korbin, New York, NY*

Find the maximum possible value of the perimeter of an integer sided triangle with in-radius $r = \sqrt{13}$.

• **5147:** *Proposed by Kenneth Korbin, New York, NY*

Let

$$x = 5N^2 + 14N + 23 \text{ and}$$
$$y = 5(N+1)^2 + 14(N+1) + 23$$

where N is a positive integer. Find integers a_i such that

$$a_1x^2 + a_2y^2 + a_3xy + a_4x + a_5y + a_6 = 0.$$

• **5148:** *Proposed by Pedro Pantoja (student, UFRN), Natal, Brazil*

Let a, b, c be positive real numbers such that $ab + bc + ac = 1$. Prove that

$$\frac{a^2}{\sqrt[3]{b(b+2c)}} + \frac{b^2}{\sqrt[3]{c(c+2a)}} + \frac{c^2}{\sqrt[3]{a(a+2b)}} \geq 1.$$

• **5149:** *Proposed by José Luis Díaz-Barrero, Barcelona, Spain*

A regular n-gon $A_1, A_2, \ldots, A_n$ $(n \geq 3)$ has center F, the focus of the parabola $y^2 = 2px$, and no one of its vertices lies on the x axis. The rays $FA_1, FA_2, \ldots, FA_n$ cut the parabola at points $B_1, B_2, \ldots, B_n$. Prove that

$$\frac{1}{n}\sum_{k=1}^{n} FB_k^2 > p^2.$$

• **5150:** *Proposed by Mohsen Soltanifar(student, University of Saskatchewan), Saskatoon, Canada*

Let $\{A_n\}_{n=1}^{\infty}, (A_n \in M_{n\times n}(C))$ be a sequence of matrices such that $\det(A_n) \neq 0,1$ for all $n \in N$. Calculate:

$$\lim_{n\to\infty} \frac{n^n \ln(|\det(A_n)|)}{\ln(|\det(adj^{\circ n}(A_n))|)},$$

where $adj^{\circ n}$ refers to $adj \circ adj \circ \cdots \circ adj$, n times, the nth iterate of the classical adjoint.

• **5151:** *Proposed by Ovidiu Furdui, Cluj, Romania*

Find the value of

$$\prod_{n=1}^{\infty}\left(\sqrt{\frac{\pi}{2}}\cdot\frac{(2n-1)!!\sqrt{2n+1}}{2^n n!}\right)^{(-1)^n}.$$

More generally, if $x \neq n\pi$ is a real number, find the value of

$$\prod_{n=1}^{\infty}\left(\frac{x}{\sin x}\left(1-\frac{x^2}{\pi^2}\right)\cdots\left(1-\frac{x^2}{(n\pi)^2}\right)\right)^{(-1)^n}.$$

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Analyses of data
Conclusions based on results
Results related to professional practice and literature
Enough information to enable replication (quantitative)

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IN THIS issue

Turkish Preservice Primary School Teachers' Science Teaching Efficacy Beliefs and Attitudes Toward Science: The Effect of a Primary Teacher Education Program

Sule Bayraktar

The main purpose of this study was to investigate the effectiveness of primary teacher education program in improving science teaching efficacy beliefs (personal science teaching efficacy beliefs and outcome expectancy beliefs) of preservice primary school teachers. The study also investigated whether the program has an effect on student teachers' attitudes toward science. Data were collected by administering the "Science Teaching Efficacy Beliefs Instrument" and "Attitudes toward Science Scale" to 282 preservice primary teachers (147 freshmen, 135 seniors). Statistical techniques such as means and *t*-test were used to analyze the data. Results of the study showed that the primary teacher education program has a medium positive effect on science teaching efficacy beliefs of the primary preservice teachers ($t = 4.791$, $p = .000$) and that there were no gender differences in terms of efficacy beliefs. Results also indicated that preservice primary teachers' attitudes toward science were moderately positive and differ by class level. Fourth-year preservice teachers' attitudes toward science were found to be significantly more positive than the first years ($t = 5.494$, $p = .000$). There were no gender differences in attitudes toward science.

Keywords: Science teaching self-efficacy beliefs; attitudes toward science; preservice primary teachers.

The Relationship of Teacher-Facilitated Inquiry-Based Instruction to Student Higher-Order Thinking

Jeff C. Marshall, Robert M. Horton

Commissions, studies, and reports continue to call for inquiry-based learning approaches in science and math that challenge students to think critically and deeply. While working with a group of middle school science and math teachers, we conducted more than 100 classroom observations, assessing several attributes of inquiry-based instruction. We sorted the observations into two groups based on whether students both explored underlying concepts before receiving explanations and contributed to the explanations. We found that in both math and science classrooms, when teachers had students both explore concepts before explanations and contribute to the explanations, a higher percent of time was spent on exploration, and students were more frequently involved at a higher cognitive level. Further, we found a high positive correlation between the percent of time spent exploring concepts and the cognitive level of the students, and a negative correlation between the percent of time spent explaining concepts and the cognitive level. When we better understand how teachers who are successful in challenging students in higher-order thinking spend their time relative to various components of inquiry-based instruction, then we are better able to develop professional development experiences that help teachers transition to more desired instructional patterns.

Keywords: Cognitive levels; critical thinking; higher-order thinking; inquiry; inquiry instruction; math education; science education.

A Mixed Method Study: Assessing the BAR Model's Impact on Preservice Teachers' Efficacy Beliefs

Ann Lyle Rethlefsen, Hyesung Park

This study took place at a mid-sized, Midwestern university located in a mid-sized town. The researchers developed the BAR model to teach mathematics methods both in the classroom and in the field. The preservice teachers took Enochs, Smith, and Huinker's (2000) Mathematics Teaching Efficacy Beliefs Instrument (MTEBI) on the first and last day of class. A total of 297 responses were collected from the pretests and posttests, with 280 matching responses, which were then used for data analysis. Mixed methods (Creswell & Tashakkori, 2007) were used to analyze qualitative and quantitative data. The researchers sought to determine if the specific teaching methods from the BAR model led to positive changes in preservice teachers' efficacy beliefs. They also explored if efficacy beliefs changed as a result of field experiences. Preservice teachers' efficacy scores changed positively on every item on the MTEBI. The researchers also determined that there was an increase

in preservice teachers' outputs as a result of their field experiences.

Data Analysis and Statistics in Middle Grades: An Analysis of Content Standards

M. Alejandra Sorto

The purpose of this study was to identify the important aspects of statistical knowledge that students in the middle school grades in United States are expected to learn as well as what the teachers are expected to teach. A systematic study of 49 states' standards and one set of national standards was used to identify these important aspects and to measure the degree of emphasis or importance suggested for the content. Results show that state and national standards differ greatly in their expectations of what topics in data analysis and statistics students and teachers should master. There is also a large variation in the degree of emphasis given to the content. The majority of the standards analyzed suggests giving greater emphasis to the selection and proper use of graphical data representation and measures of center.

Turkish Preservice Primary School Teachers' Science Teaching Efficacy Beliefs and Attitudes Toward Science: The Effect of a Primary Teacher Education Program

Sule Bayraktar
Selcuk University

The main purpose of this study was to investigate the effectiveness of a primary teacher education program in improving science teaching efficacy beliefs (personal science teaching efficacy beliefs and outcome expectancy beliefs) of preservice primary school teachers. The study also investigated whether the program has an effect on student teachers' attitudes toward science. Data were collected by administering the "Science Teaching Efficacy Beliefs Instrument" and "Attitudes toward Science Scale" to 282 preservice primary teachers (147 freshmen, 135 seniors). Statistical techniques such as means and t-test were used to analyze the data. Results of the study showed that the primary teacher education program has a medium positive effect on science teaching efficacy beliefs of the primary preservice teachers ($t = 4.791$, $p = .000$) and that there were no gender differences in terms of efficacy beliefs. Results also indicated that preservice primary teachers' attitudes toward science were moderately positive and differ by class level. Fourth-year preservice teachers' attitudes toward science were found to be significantly more positive than the first years ($t = 5.494$, $p = .000$). There were no gender differences in attitudes toward science.

Teachers' sense of efficacy beliefs is a construct derived from Bandura's (1977) theory of self-efficacy in which the generalized behavior of an individual is based upon two factors: (a) a belief about action and outcome (outcome expectancy belief); and (b) a personal belief about one's ability to cope with a task (self-efficacy belief) (Çakıroğlu, Çakıroğlu, & Boone, 2005). Bandura proposed that self-efficacy beliefs are constructed from four particular sources: *mastery experiences*, *vicarious experiences*, *verbal persuasion*, *and physiological and emotional states*. Mastery experiences are individuals' past successes or failures on executing a task. Vicarious experiences are experiences in which individuals compare themselves to peers whom they perceive are similar in ability and intelligence to themselves. Observing peers' successful performances raises observer self-efficacy, and seeing them fail lowers it. Verbal persuasion refers to social messages that are reported by people around the individual about his or her ability to perform the task successfully. Social messages motivate people to put more effort on the task and improve their skills. However, if individuals with low self-esteem are reported that they cannot be successful in the task, this might have the most destructive effect on them. Emotional states such as anxiety and stress also affect individuals' self-efficacy beliefs. Depending on the mood, emotional arousal might be a motivating power to successfully perform a task, or it might result in a total failure (Bandura). Mastery experiences are considered the most powerful source of self-efficacy information, although all the four factors affect the perceptions of self-efficacy if presented appropriately (Tschannen-Moran, Hoy, & Hoy, 1998).

Bandura's work on efficacy has impacted educational research as well as other academic disciplines. Researchers investigated the effect of efficacy beliefs on different variables related to teaching and learning in various subject areas. As Bandura asserted, individuals' efficacy beliefs are subject dependent. The present research is related to science teaching efficacy beliefs of preservice primary teachers. Preservice teachers' science teaching efficacy beliefs can be defined as a combination of their confidence in their capabilities to teach science effectively (*personal science teaching efficacy* [PSTE] *beliefs*) and the beliefs that student learning can be influenced when effective teaching methods are employed (*science teaching outcome expectancy* [STOE]). Studies about science teaching efficacy beliefs revealed that they are among the most important factors that influence teacher behavior and student achievement. These studies have shown that teachers with low PSTE beliefs spend less time on teaching science (Harlen &

Holroyd, 1997; Ramey-Gassert & Shroyer, 1992; Westerback & Long, 1990), use teacher-centered methods such as lecture, and rely on textbook, while high-efficacious teachers utilize student-centered teaching strategies such as activity-based instruction and inquiry-based instruction (Anderson & Roth, 1989; Enochs, Scharmann, & Riggs, 1995). Low-efficacious teachers are more likely to adopt didactic approaches instead of conceptual understanding (Anderson & Roth; Appleton & Kindt, 1999). Furthermore, a two-way interaction was detected between teacher efficacy and student achievement. That is, teachers of the successful students become more self-efficacious, and the students of teachers who are high-efficacious become more successful (Rimm-Kaufman & Sawyer, 2004). Considering all these findings, helping teacher candidates to develop a high level of self-efficacy beliefs should be one of the most important tasks for teacher educators.

Attitude is commonly defined as a predisposition to respond positively or negatively toward things, people, places, events, and ideas (Koballa, 2007). Attitudes are not behaviors; rather, they are powerful psychological variables that affect behavior. Fishbein and Ajzen (1975) proposed that attitudes and subjective norms combine to determine behavioral intentions, which in turn cause behaviors. According to this theory, a student's belief that "science is a difficult subject that he can not possibly be successful" results in an attitude of hating science. This attitude consequently results in a behavior such as avoidance of attending science classes and not doing class works. However, an attitude of "enjoyment of science" might lead to not missing a single science class or reading publications related to science (Yılmaz, Yalvaç, & Tekkaya, 1998).

Parents and teachers play an important role on students' attitudes toward science. However, research studies have shown that many primary preservice teachers dislike science (Abell & Smith, 1994; Lloyd et al., 1998; Mulholland & Wallace, 1996; Schoon & Boone, 1998). This is an important problem because preservice teachers who hold these attitudes are likely to avoid teaching science, or teach it poorly, when they become teachers (Harlen & Holroyd, 1997; Skamp, 1989); also, they generally employ didactic approaches rather than inquiry-based activities (Abell & Smith; Appleton & Kindt, 1999; Bencze & Hodson, 1999; Harlen & Holroyd), and finally, it is possible that they pass on negative attitudes to their students (Czerniak & Chiarelott, 1990; Westerback, 1982). It is therefore necessary to identify preservice primary teachers who hold negative attitudes toward science and find ways to help them to develop more positive attitudes before they start to teach in schools.

Primary teacher education programs at Turkish universities are four-year-long undergraduate programs, and their common curriculum is designed by the Higher Education Council (Yüksek Öğretim Kurulu, YÖK). Turkish primary school teacher candidates take science content courses in their first two years: biology (three credits), chemistry (three credits), physics (three credits), environmental science (two credits), and science laboratory (two credits). Furthermore, student teachers take science methods courses in their third year of study. Science methods courses in teacher preparation programs are designed for preservice teachers to develop their skills and knowledge required to best practice student teaching in their future schools. However, the method course does not include a practicum component that requires preservice teachers to teach science lessons at an elementary school classroom; neither does the program include a separate science practicum course. However, preservice primary teachers practice student teaching during their fourth year. For a minimum of 12 weeks, Turkish preservice teachers are required to attend elementary schools for one full day or two half days. During their practicum, however, they do not have a chance to choose a particular subject matter; rather, they practice every school subject taught in primary schools. For this reason, they have limited experiences for teaching science as well as the other subject matters. Upon successful completion of the undergraduate program within eight semesters, Turkish preservice teachers receive primary school teaching licensure to teach at the one to five grades in all public and private elementary schools (YÖK, 1998). The aim of this study is to evaluate the effectiveness of a teacher education program in Turkey on preservice primary school teachers' science teaching efficacy beliefs.

The effects of teacher education programs (specifically science courses and science methods courses) on science teaching efficacy beliefs of preservice primary school teachers have been well documented in the literature. However, these studies are conducted generally in a few countries such as the United States and the UK. Different teacher education programs might have different impacts on science teaching efficacy beliefs. Thus, a contribution of this study would be adding new data to the literature, which might be

useful in comparing the effectiveness of different teacher training programs regarding science teaching efficacy beliefs and attitudes toward science.

Purpose of the Study

The purposes of this study were to investigate the effectiveness of a primary teacher education program on science teaching efficacy beliefs (PSTE and outcome expectancy) and attitudes toward science, and to determine whether these beliefs and attitudes vary by gender.

Methodology

The sample of this study consisted of 282 preservice primary teachers (147 freshmen and 135 seniors). Preservice primary teachers' efficacy beliefs and attitudes toward science were explored by employing Likert-type scales. Preservice teachers' science teaching self-efficacy beliefs were measured by administering the Turkish version of the Science Teaching Self Efficacy Beliefs Instrument (STEBI-B), which was developed by Enochs and Riggs (1990) specifically for preservice teachers. The original STEBI-B consists of 23 items in a five-point Likert-type scale ranging from strongly agree to strongly disagree and has two subscales: PSTE, including 13 items, and STOE, including 10 items. High scores on the first scale, relative to other respondents, indicate a strong personal belief in one's own efficacy as a science teacher, and high scores on the second scale indicate high expectations of the outcomes of science teaching.

The STEBI-B was adapted to Turkish by Bıkmaz (2002), and it was established that the Turkish version is a valid and reliable instrument. Bıkmaz conducted a factorial analysis, which revealed that the factorial structure of the STEBI-B developed by Enochs and Riggs (1990) was the same as that observed for the Turkish sample. Two items were deleted from instrument because of low factor loadings. Finally, the Turkish version of STEBI-B consists of 21 items, and the PSTE subscale includes 13 items, and STOE subscale includes 8 items. Reliability coefficients for the PSTE and STOE were calculated as .89, and .69, respectively. The results of these analyses indicate that the STEBI-B could be considered as a reasonable instrument to produce valid and reliable data. Cronbach alpha was calculated as .81 and .69 for PSTE and STOE, respectively, for the present study ($N = 282$).

Preservice teachers' attitudes toward science were explored by means of a five-point Likert-type attitude scale ranging from 1 to 5, with 5 being "strongly agree" and 1 being "strongly disagree." "Attitudes toward Science Scale" was developed by using a number of items from various attitudes scales (Francis & Greer, 1999; Menis, 1989; Ornstein, 2006). The scale consists of 34 items. There are 22 positive statements such as "Science is an enjoyable school subject" and 12 negative statements such as "Scientific discoveries do more harm than good" in the scale. Cronbach's alpha of the scale was .92 for the present study.

The construct validity of the attitude scale was tested by using factor analysis. Kaiser–Meyer–Olkin coefficient was found as .872, which indicated that the sample was adequate to use factor analysis. Bartlett test revealed a significant chi-square value ($\chi^2 = 2604.328$, $df = 561$, $p = .000$). These findings suggest that the level of correlation between scale items is enough for conducting a factor analysis on the sample. Principle components analysis method was used for factor analysis. In order to determine the significant factors, eigen values greater than 1 and the variance explained by the factor were looked at. The factor analysis revealed a five-factor structure, which explains 62.335% of the total variance. The evaluation of the results from the factor analysis was done based on the factor loadings. The items' factor loadings ranged between .426 and .810. These results suggest that the Attitudes toward Science Scale is a valid instrument in this study.

In analyzing the data, for both variables, the normality test was performed within each group. After establishing the normality condition, statistical techniques such as means and *t*-test were used to analyze the data. In order to investigate the effectiveness of the preservice primary education program on science teaching efficacy beliefs of preservice teachers, scores on the STEBI-B (STOE and PSTE) were compared for the first- and last-year preservice teachers by utilizing the *t*-test. The same procedure was followed also for the scores on Attitudes toward Science Scale. The scores of male and female students on both tests were also compared to see whether there is a gender difference in science teaching efficacy beliefs and attitudes toward science. Means for each item of STEBI-B and the Attitudes toward Science Scale were calculated to see specifically which areas are problematic in terms of self-efficacy and attitudes. Alpha was set at .05 level of significance for all tests. Effect sizes were also calculated for each analysis to see the magnitude of the effect of the primary education program on

Table 1
Independent Means and t-Test Results Between Freshmen and Seniors on PSTE

Grade Level	*N*	Mean	*SD*	*t*	Significance	Effect Size
1	147	2.66	.49	3.81	.000	.455
4	135	2.91	.57			

preservice teachers' science teaching efficacy beliefs. Effect size ("d") was calculated by using the method of Cohen. Cohen's *d* is defined as the difference between two means divided by a standard deviation for the data. For Cohen's *d*, an effect size of .2–.3 might be a "small" effect, around .5 might be a "medium" effect, and .8 to infinity might be a "large" effect.

Results

Self-Efficacy

The results of the study showed that student teachers' science teaching efficacy beliefs are moderately positive ($\bar{X} = 3.01$). Examination of the beliefs in terms of the two subscales, PSTE and STOE, revealed different results. Student teachers' PSTE scores were found to be relatively low ($\bar{X} = 2.78$). Results of the study showed that there is a statistically significant difference between senior and freshmen preservice teachers that is in favor of seniors (see Table 1). An effect size of .455 was found for difference in efficacy beliefs and indicates that years of training had made a moderate effect on preservice teachers' science teaching efficacy beliefs. Results also indicated that there were no gender differences in terms of PSTE scores ($t = 3.81$, $p > .05$).

Item-by-item analysis revealed that fourth-year primary education students were most confident in their abilities about welcoming student questions ($\bar{X} = 3.81$) and answering questions ideally ($\bar{X} = 3.64$). Following these two, they were relatively more confident in their abilities about knowing the related concepts to teach science effectively ($\bar{X} = 3.34$) and knowing necessary steps to teach science ($\bar{X} = 3.32$). The preservice teachers were less confident about their abilities related to designing science experiments ($\bar{X} = 2.39$) and directing students to science areas ($\bar{X} = 2.26$). Because these items were negatively worded, the items with a mean of greater than 2 were considered as less confident areas.

Table 2
Independent Means and t-Test Results Between Freshmen and Seniors on STOE

Grade Level	*N*	Mean	*SD*	*t*	Significance
1	147	3.22	.48	.79	.461
4	135	3.26	.49		

The results of the study showed that preservice teachers' STOE beliefs are relatively more positive ($\bar{X} = 3.24$) than their PSTE beliefs, and there were no significant differences between first-year and fourth-year student teachers (see Table 2), as well as males and females.

Attitudes

The results of the study showed that preservice teachers' attitudes toward science were positive in general ($\bar{X} = 3.24$). There were no significant differences between male and female preservice teachers regarding attitudes toward science. However, a statistically significant difference was found between first-year and fourth-year preservice teachers' attitudes toward science, with seniors' attitudes being more positive than freshmen ($t = 5.494$, $p = .000$). The effect size was found to be .595 for attitudinal difference, suggesting that a moderate size change occurred in student teachers' attitudes toward science during the years of training.

Table 3 indicates that mean scores of seniors on attitudes toward science are significantly greater than freshmen primary education students.

Discussion

The results of this study showed that preservice primary teachers' science teaching efficacy beliefs and attitudes toward science evolved through their training at the primary education program. This result is consistent with studies done in Turkey (Gerçek, Yılmaz, Köseoğlu, & Soran, 2006; Savran &

Table 3
Independent Means and t-Test Results Between Freshmen and Seniors on Attitudinal Difference Toward Science

Grade Level	*N*	Mean	*SD*	*t*	Significance	Effect Size
1	147	2.96	.55	4.98	.000	.595
4	135	3.32	.66			

Çakıroğlu, 2003; Üredi & Üredi, 2006; Yaman Cansüngü-Koray & Altunçekiç, 2004) and other countries (Bleicher & Lindgren, 2005; Czerniak & Chiarelott, 1990; Westerback & Long, 1990). The training period at the faculty of education had a positive medium effect on the preservice primary teachers' attitudes toward science and their PSTE beliefs. It appears that science subject courses, science laboratory, and the science methods course included in the curriculum affected preservice teachers' attitudes and PSTE beliefs positively. However, the magnitude of the change in science teaching efficacy beliefs and attitudes toward science cannot be considered sufficient. More effort is needed to improve the effectiveness of the teacher education program. A reevaluation of the program components and an examination of the interrelationships between the program components might also be considered.

The results for fourth-year students revealed that they felt moderately self-efficacious in science teaching. The preservice teachers are most confident about their abilities in welcoming and answering students' science questions. This finding is consistent with Çakıroğlu et al.'s (2005) study, which compares American and Turkish preservice teachers on science teaching efficacy beliefs, reporting that Turkish preservice teachers were more confident about their abilities in answering science questions than their American counterparts. The second area that the preservice teachers are confident about their abilities was their knowledge in science topics and science teaching methods. According to the results, the preservice primary school teachers believe that they acquire the science concepts and the knowledge of methods of teaching at a sufficient level. However, the mean score on the item "I will generally teach science ineffectively" for fourth-year students shows that they are not confident enough when it comes to teaching. This discrepancy could be explained by the fact that they have limited experiences of teaching science to schoolchildren in real classrooms. This result confirmed the results of studies that showed that teaching efficacy beliefs are correlated to amount of field experiences (Cannon, 1999; Cantrell, Young, & Moore, 2003; Lind, Kingsley, & Gordon, 2001).

There are various studies demonstrating that science methods course is one of the most important factors affecting PSTE beliefs positively. These studies explained this effect by the role of it in establishing the four sources of self-efficacy. Yet effectiveness of the methods course mostly depends on its practicum content. Researchers indicate that the effect of practicum is related to its ensuring the four sources of self-efficacy. Preservice teachers acquire mastery experiences by teaching science to children in real classrooms and vicarious experiences by observing their peers and the in-service teachers when teaching schoolchildren science. Verbal persuasion comes from the teachers of the classrooms they teach and their science methods course instructors. As indicated earlier in this article, preservice primary school teachers in Turkey do not have a separate science teaching practicum course. Although they have student teaching practicum at their last year, they have to practice in all subject areas; therefore, they have insufficient amount of experience with the students in a real classroom teaching science. Because primary school teachers in Turkey teach almost all subject matters included in the curriculum to first- to fifth-grade students, they are required to be knowledgeable in many subject areas. During student teaching period, they try to practice in all subject matters taught in primary schools. This situation naturally limits the time period allocated for each subject matter, therefore not making any contribution in improving their efficacy beliefs. Yılmaz and Huyugüzel-Cavas's (2008) study supports this conclusion, which revealed that teaching practicum did not contribute to Turkish preservice primary teachers' science teaching efficacy beliefs. A separate practicum opportunity specifically for

science teaching might have a positive impact on science teaching efficacy beliefs of preservice primary teachers.

By looking at the results of the study, nothing could be said about the specific roles of the science courses, the methods course, and the teaching practicum in improving the science teaching efficacy beliefs and the attitudes of preservice primary teachers toward science, because the comparisons were made for the first- and fourth-year students only; rather, the combined effect of them could be discussed. In this sense, the results of this study are consistent with other studies done on the subject demonstrating that preservice primary teachers' PSTE beliefs developed through teacher training period by the influence of either the methods course or the science course in Turkey (Bursal, 2008; Üredi & Üredi, 2006; Yaman et al., 2004) and in other countries (Cantrell et al., 2003; King & Wiseman, 2001; Morrell & Carroll, 2003).

Laboratory experiments were perceived to be one of the less confident areas by the preservice primary teachers. The reason for this might be related to the practices in their science laboratory course. Generally, preservice teachers work as a group when doing laboratory experiments. For this reason, group members might not have equal experiences in the process. This situation might cause them to feel unconfident about knowing and using the laboratory equipment, and performing the experiment successfully. This problem could be solved if the laboratories are supplied with sufficient material and equipment, and sufficient number of laboratory instructors, and by spending more hours to study. Furthermore, laboratory course could include a part that involves designing experiments for fourth- and fifth-grade science and technology curriculum. Requiring preservice teachers to do experiments that are already designed specifically for these grades in the laboratory environment could also be useful.

Outcome expectancy beliefs were found to be more positive than the personal efficacy beliefs for these particular preservice teachers and did not change during their education in the program. Many other studies have shown that science courses and science methods courses did not affect outcome expectancy beliefs (Çakıroğlu et al., 2005; Morrell & Carroll, 2003; Roberts, Henson, Tharp, & Moreno, 2001; Tosun, 2000).

The results of the study showed that preservice teachers' attitudes toward science were moderately positive. Results of the study also showed that preservice teachers' most positive attitudes toward science are in the dimension of importance and usefulness of science. While preservice teachers believe that science is important for a country's development and prosperity in a great extent, their interest in and enjoyment toward science were not at the desired level. The reason of this finding might be related to science classes they took in their secondary school years and their achievement in science classes. In fact, Baykul's (1990) study showed that in Turkey, although children enjoy science and have interest toward science in their primary school years, they lose their interest and motivation, and start to dislike science classes in their secondary school years as a result of perceiving science classes as difficult. Consequently, they start to avoid science classes and shift to social sciences. These students choose the social sciences track over science in their secondary school years so that they do not have to take science classes any more. Primary education students generally have social sciences background. A small proportion of students come from the science track.

Although preservice teachers' enjoyment and motivation toward science are relatively poor, their enjoyment level of experiments and hands-on activities is remarkably higher. Indeed, some studies (Freedman, 1997; Ornstein, 2006) revealed that hands-on activities and experiments have positive effects on students' attitudes toward science.

There were no significant differences between male and female preservice teachers' attitudes toward science in this study. This result confirmed the results of Turkish studies done on the same topic (Bilgin & Geban, 2004; Tekbıyık & İpek, 2007; Türkmen, 2002). This issue is controversial in the international studies. For example, a study with preservice teachers from Taiwan did not find any significant gender differences in attitudes toward science (Chin, 2005). However, many studies done in different countries reported significant gender differences in attitudes toward science in favor of male students (George, 2006; Weinburgh, 1995). In Turkey, having no gender differences in attitudes toward science might be interpreted as science not being regarded as a male domain in the Turkish culture. Indeed, professions are not discriminated as being a male or female profession in Turkey. This attitude can be observed more easily by looking at enrollment rates of some college departments that can be regarded as highly scientific subjects. Female student proportion of physics departments, for

example, is higher than in many developed countries. In fact, as Baker (1998) reported, Turkey has a higher proportion of women in science and medicine than Western countries, and this could be interpreted as science not having a masculine image in Turkey.

A statistically significant difference was found between first-year and fourth-year preservice teachers' attitudes toward science, with seniors' attitudes being more positive than freshmen ($t = 5.494$, $p = .000$). This result suggests that the primary teacher education program makes a difference in preservice students' attitudes toward science. It appears that science subject courses, science laboratory, and the science methods courses in the curriculum affected preservice teachers' attitudes positively. Students taking these classes, via their own experiences, might have felt that science classes are not as difficult and scary as they expected. Furthermore, especially by means of the activities they do in methods courses, they might have understood how science is related to everyday life and feel also that it is fun.

This result is confirmed by the studies on the topic. For example, Chin (2005) revealed that first-year elementary teachers hold relatively less positive attitudes toward science when compared with last-year teachers. Tekbıyık and İpek (2007) also revealed that first-year primary education students' attitudes toward science were significantly poorer than the upper year students. Other studies indicated that the science-related courses and science method course have a positive effect on preservice teachers' attitudes toward science (Pedersen & McCurdy, 1992; Stefanich & Kelsey, 1989).

Conclusion and Recommendations

This study revealed that preservice primary teachers' science teaching efficacy beliefs and attitudes toward science evolved through their training at the primary education department. This result suggests that the primary teacher education program, which was followed by the participants of the present study, is successful to some degree in improving science teaching efficacy beliefs and attitudes toward science. However, which component of the program is more influential on the efficacy beliefs and attitudes could not be made explicit. Investigating the specific effects of the different components of the program such as science subject courses, science methods course, and practicum would be useful to reach a more specific conclusion on which components need to be improved.

Although the program is shown to be effective in improving the efficacy beliefs and attitudes, the improvement does not seem sufficient for this particular sample because the final-year preservice teachers' scores on self-efficacy beliefs and attitudes are relatively low. This result implies that there is an urgent need to think about the ways for improving the preservice primary teachers' science teaching efficacy beliefs and their attitudes toward science. As stated earlier, knowing the degree of contribution of each possible factor would be quite helpful on developing ideas to better improve student teachers' efficacy beliefs. Although this kind of information is not available at the moment, by synthesizing the information about this specific teacher education program and the information provided from the literature, the author hypothesizes that the most important deficiency for this particular program is its not having a separate science teaching practicum. Incorporating this component to the science methods course might be an effective way of increasing the efficacy beliefs. Preservice teachers' science teaching efficacy beliefs might also be improved by employing student-centered approaches more often in their science courses. For preservice teachers, learning science in a meaningful way improves their efficacy beliefs. Student teachers realize this kind of learning in a constructivist learning environment in which they can actively discuss, make real-world connections, and transfer their knowledge in different areas (Bleicher & Lindgren, 2005; Brandon, 2000; Posnanski, 2002; Roberts et al., 2001).

The improvement in the preservice teachers' attitudes toward science was not found to be visible. In order to reach a better improvement level, there are certain factors to be considered seriously. According to the results of the study by Palmer (2001), for example, personal attributes of the instructor (e.g., confidence and enthusiasm), specific learning strategies (e.g., science trivia, personal anecdotes, dramatizations, and demonstrations), and external validation (the evidence that the techniques that the preservice teachers learned in the course worked with children in real classrooms) are reported to be the most influential factors on converting preservice teachers' attitudes from negative to positive. McDevitt, Heikkinen, Alcorn, Ambrosio, and Gardner (1993) maintained that content courses should be taught using methods that relate concepts and built upon students' experiences, paying particular attention to science concept

development and overcoming alternative conceptions. If this cannot be done in science content courses, then it must be done in the science methods course. Incorporating courses of philosophy of science and history of science in the curriculum might also be beneficial in developing more positive attitudes in preservice primary teachers (Özden, 2007).

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Author's Note

Keywords: Science teaching self-efficacy beliefs; attitudes toward science; preservice primary teachers.

The Relationship of Teacher-Facilitated, Inquiry-Based Instruction to Student Higher-Order Thinking

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Commissions, studies, and reports continue to call for inquiry-based learning approaches in science and math that challenge students to think critically and deeply. While working with a group of middle school science and math teachers, we conducted more than 100 classroom observations, assessing several attributes of inquiry-based instruction. We sorted the observations into two groups based on whether students both explored underlying concepts before receiving explanations and contributed to the explanations. We found that in both math and science classrooms, when teachers had students both explore concepts before explanations and contribute to the explanations, a higher percent of time was spent on exploration and students were more frequently involved at a higher cognitive level. Further, we found a high positive correlation between the percent of time spent exploring concepts and the cognitive level of the students, and a negative correlation between the percent of time spent explaining concepts and the cognitive level. When we better understand how teachers who are successful in challenging students in higher-order thinking spend their time relative to various components of inquiry-based instruction, then we are better able to develop professional development experiences that help teachers transition to more desired instructional patterns.

For well over a decade, there has been a clear push toward instructional practices that facilitate critical, deep thinking of students. Wiggins and McTighe (1998) call this a focus on *enduring ideas*, mathematics education leaders call this a focus on *big ideas* (National Council of Teachers of Mathematics [NCTM], 2006), and science education leaders call this a focus on *unifying concepts and process* (National Research Council [NRC], 1996). Whatever the terms chosen, for students to excel in tomorrow's world, they must be equipped to solve complex problems instead of just memorizing algorithms or definitions (Friedman, 2005; National Academy of Sciences, 2007; NCTM, 2000). Whether we look internationally through the lens of the TIMSS (Schmidt, McNight, & Raizen, 2002) and PISA (Baldi, Jin, Skemer, Green, & Herget, 2007), or nationally through the NAEP scores (Grigg, Lauko, & Brockway, 2006; Lee, Grigg, & Dion, 2007), the data indicate that our nation's schools and classrooms have not been successful in helping most students become better critical thinkers and problem solvers.

Theoretical Framework

Numerous models of inquiry-based instruction have been espoused (Atkin & Karplus, 1962; Bybee et al., 2006; Marshall, Horton, & Smart, 2009; NRC, 2000). Despite what are often subtle differences (e.g., the number of steps or components associated with model, naming differences), all of the models exhibit some uniformity in what needs to occur during inquiry instruction and learning. Specifically, the learner needs to be perturbed, a Piagetian notion (Piaget, 1970), in a way that draws upon students' prior knowledge and understanding (Bransford, Brown, & Cocking, 2000). Vygotsky's (1978) zone of proximal development added the importance of scaffolding learning. This allows students to perform in the region or zone where they can be challenged to think critically without being overwhelmed. Effective inquiry learning environments provide an active setting for students that provides essential scaffolding based on each student's readiness and current ability. Such learning environments are foundational to differentiating instruction (Tomlinson & McTighe, 2003) and challenging students to think critically and analytically.

Another similarity among inquiry-instructional models is the importance placed on developing deep conceptual knowledge over surface, rote learning. Thus, successful facilitation of inquiry-based instruction necessitates a shift from either of two extremes

that dominate many of our classrooms: an activity mania in which students are kept occupied but only at superficial levels (Moscovici & Holdlund-Nelson, 1998) or teacher-dominated lecture in which instructors try to pour knowledge into their students' heads. Instead, successful inquiry leads to a deeper, more thoughtful interaction with the underlying concepts (Donovan & Bransford, 2005; Llewellyn, 2002; NRC, 2000). Meaningful inquiry investigations bring students to a point of deep understanding regarding a key concept in the discipline.

Several curricula have been designed to promote higher-order thinking through inquiry-based learning (e.g., Biological Science Curriculum Study, National Science Resource Center, FOSS Project, The GLOBE Program, Connected Math, Math-Thematics), but the single greatest factor in improving student academic achievement is the quality of the teacher, ceteris paribus (Sanders & Rivers, 1996). Therefore, teachers need to be equipped to facilitate investigations and conversations that help students to analyze instead of recall, to justify instead of define, and to formulate instead of list. Many instructional strategies exist, but inquiry instruction is the sole strategy investigated for this study primarily because it is one of the eight core National Science Standards (NRC, 1996), and it is integral to all five of the National Mathematics process standards (NCTM, 2000).

The Problem

This study analyzed data from 102 classroom observations of middle school math and science teachers to understand if the amount of time spent on various components of inquiry or the order that these components are presented to students is related to the cognitive level at which students are expected to work and learn. Four components are present in many of the currently used inquiry instructional models (Bybee et al., 2006; Eisenkraft, 2003; Marshall et al., 2009): Engage (when misconceptions and prior knowledge are exposed), Explore (when a learner actively and thoughtfully investigates a scientific question or concept), Explain (when prior knowledge is united with learning from the current investigation in an effort to resolve disequilibrium and generate conceptual understanding), and Extend (time when learning is deepened and applied to new situations or previous concepts). It is important to note that the student must be actively involved during both the Explore and Explain components of the learning process. During the Explain, students must actively participate in making sense of the data gathered during the Explore. Teachers' roles become that of facilitators to probe, question, and help draw the pieces together.

If, as previously mentioned, teacher quality is critical to improving student performance, then it is important to understand how the instruction facilitated results in higher cognitive performance of students. As such, the following questions were asked relative to the previously stated larger research objective:

1. How does the order of instruction relate to the time spent on the Explore and Explain components of inquiry?
2. How does the order of instruction facilitated relate to the cognitive level displayed by students?
3. What is the relationship between the amount of time spent exploring and explaining concepts and the cognitive level displayed by students?

Explain and Explore are the central focus of this study because our pilot work showed that when inquiry instruction was occurring in the classroom, they comprised the vast majority of instructional time. By understanding how the order of instruction and the amount of time explaining and exploring are related to the cognitive level at which the students are engaged, we will gain insights into how teachers can more effectively implement inquiry-based instruction.

Method

During the fall 2009 semester, 102 full-length classroom observations (60 science and 42 mathematics) were made. The 22 participating teachers (12 science and 10 mathematics) came from two middle schools within a large Southeastern urban district. All teachers were part of a yearlong professional development institute designed to support teachers as they transform their practice to more inquiry-based learning approaches. A mean of 4.4 observations were made for each teacher—the number varied depending on the schedules and availability of teachers.

Observation Instrument

All classroom observation data were gathered using the Electronic Quality of Inquiry Protocol (EQUIP; Marshall, Horton, Smart, & Llewellyn, 2008; Marshall, Horton, & White, 2009), a valid and reliable instrument designed to measure the quantity and quality of inquiry instruction being implemented. EQUIP measures 6 indicators at five-minute intervals and then 19 indicators at the conclusion of the

Construct measured	*Pre-inquiry (Level 1)*	*Developing inquiry (Level 2)*	*Proficient inquiry (Level 3)*	*Exemplary inquiry (Level 4)*
Order of Instruction	Teacher explained concepts. Students either did not explore concepts or did so only after explanation.	Teacher asked students to explore concept before receiving explanation. Teacher explained.	Teacher asked students to explore before explanation. Teacher and students explained.	Teacher asked students to explore concept before explanation occurred. Though perhaps prompted by the teacher, students provided the explanation.

Figure 1. Portion of descriptive rubric detailing order of instruction (Marshall et al.; 2008; Marshall, Horton & White, 2009).

observation. The 19 indicators address four major constructs: Instruction, Discourse, Assessment, and Curriculum. For this manuscript, we used the *Order of Instruction* indicator under the Instruction construct (see Figure 1 for the rubric) to track the progression of the instruction. Of the indicators measured at five-minute intervals, two were central to this study: *Cognitive Level* of students and *Component of Inquiry* being investigated (see Figure 2 for the rubric of each). We then computed an approximate percent of time dedicated to each category (e.g., Explore, Explain) for both of these indicators.

Data Analysis

Using the *Order of Instruction* observational indicator (see Figure 1), teachers' lessons were divided into two groups: a higher-performing group (lessons earning Level 3 or 4) and a lower-performing group (earning Level 1 or 2). We then used Z-tests to compare the two groups on each of the possible values for the two variables mentioned above: (1) the *Cognitive Level* engaged in by students and (2) the *Components of Inquiry* facilitated by the teacher. We conducted this analysis for the five *Cognitive Levels* (Level 0, 1, 2, 3, and 4 and above) and for the five *Components of Inquiry* (Noninquiry, Engage, Explore, Explain, and Extend).

Correlation of Components of Inquiry Facilitated and Cognitive Level of Students. Because the *Order of Instruction* indicator focuses largely on whether teachers have their students both Exploring underlying concepts before fully Explaining and contributing to the Explanations, we conducted a deeper analysis of the Explore and Explain *Components of Inquiry*. Specifically, we sought correlations, using Pearson's r, for all 102 lessons, for the 60 science lessons, and for the 42 math lessons between the number of five-minute segments during which Explore and Explain were the dominant *Components of Inquiry* facilitated and the number of five-minute segments devoted to higher and lower-order *Cognitive Levels* by students. Higher interrater agreement among the four reviewers ensured that measurements were reliable. Both the interrater agreement and the validity of the instrument being used was previously justified in prior work (Marshall, Smart, & Horton, 2010).

Results

Order of Instruction

When instruction provided opportunities for students to Explore concepts before a full Explanation occurred and when students were involved in the Explain portion of the lesson, the lessons earned a proficient rating or above (Level 3 or 4) for the indicator entitled *Order of Instruction* (see Figure 1). Of the 102 lessons observed, 46 earned a proficient or above rating (Levels 3 or 4), while 56 were rated as developing or below (Level 1 or 2). We then investigated the differences between the two groups on the percent of time devoted to different *Components of Inquiry* and on the *Cognitive Level* displayed by students.

Time Spent on Components of Inquiry. Figure 2 describes the *Components of Inquiry* that we coded

Cognitive Level—displayed by students
0. Other–e.g., classroom disruption, noninstructional portion of lesson, administrative activity
1. Receipt of knowledge
2. Lower order (recall, remember, understand) and/or activities focused on completion exercises, computation
3. Apply (demonstrate, modify, compare) and/or activities focused on problem solving
4. Analyze/Evaluate (evidence, verify, analyze, justify, interpret)
5. Create (combine, construct, develop, formulate)
Components of Inquiry—facilitated by teacher
0. Noninquiry: activities with the purpose of skill automation; rote memorization of facts; drill and practice; checking answers on homework, quizzes, or classwork with little or no explanation
1. Engage: typically situated at the beginning of the lesson; assessing student prior knowledge and misconceptions; stimulating student interest
2. Explore: students investigate a new idea or concept
3. Explain: teacher or students making sense of an idea or concept
4. Extend: students apply ideas to a new contextual setting or investigate concepts in greater depth

Figure 2. Explanation of codes used to assess quality of inquiry (Marshall et al., 2008; Marshall, Horton, & White, 2009).

during our observations. We found significant differences between the two groups of lessons on the percent of time allocated to the Noninquiry and to Explore components of the lesson (see Table 1 and Figure 3). During lessons that scored Level 3 or 4 on *Order of Instruction*, teachers spent 10.2% of their time on Noninquiry forms of instruction vs. 26.4% of the time for lessons earning Level 1 or 2. In a similar manner, for lessons that earned Level 3 or 4, teachers spent 36.8% of their time facilitating Explorations with their students, which is significantly different from the 19.9% of time spent by teachers whose lessons earned Level 1 or 2. Further, we found that 47.8–52.2% of the middle of the lesson (21–40 minutes from the beginning) was spent on Exploration for lessons that earned Level 3 or 4 compared with only 23.2–28.6% of that time for lessons that earned Level 1 or 2.

No significant differences were noted between the two groups of lessons (based on *Order of Instruction*) regarding the time allocated for the Engage, Explain, and Extend portions of the lesson. Even though the percent of time was similar between the two groups of lessons on the Explain *Component of Inquiry* instruction, the rubric to distinguish the two groups clearly suggests that differences exist in how the time is spent during the Explain portion of the lesson, as students must be involved with the Explanation for a lesson to achieve the higher rating.

Cognitive Activity of Students. Knowing the relative percent of time spent on various *Components of*

Table 1
Z-Scores Comparing Relative Percent of Time Spent on Various Measures

Measure	Mean for Group Scoring 1 or 2	Mean for Group Scoring 3 or 4	*Z*-score
Inq 0 (Noninquiry)	26.37	10.21	7.299***
Inq 1 (Engage)	14.02	15.59	0.796
Inq 2 (Explore)	19.90	36.77	6.872***
Inq 3 (Explain)	36.29	35.10	0.445
Inq 4 (Extend)	3.42	2.32	1.597
Cog. Level 0	8.46	5.35	2.164*
Cog. Level 1	23.66	9.73	6.526***
Cog. Level 2	44.71	27.88	6.23***
Cog. Level 3	20.66	35.70	6.083***
Cog. Level 4 or >	2.56	21.33	11.038***

* $p < .05$; *** $p < .001$.

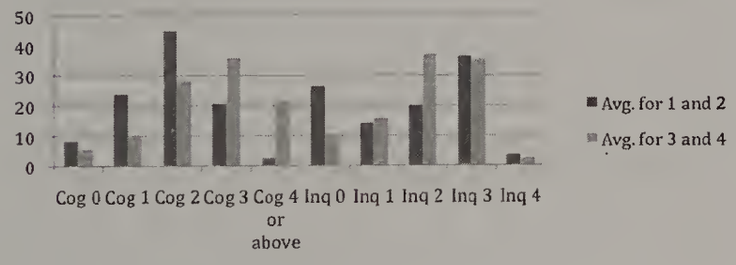

Figure 3. Percentage of time spent on each cognitive level and component of inquiry.

Inquiry is informative for guiding instructional practice during in-service and preservice discussions, but deeper analysis of the data revealed more about the quality of the instruction during the lesson. Specifically, the *Cognitive Level* displayed by all students for a given class, sampled at five-minute intervals, was also significantly different for the two groups of lessons. Specifically, teachers' lessons that earned Level 3 or 4 on *Order of Instruction* spent 57.0% of their time facilitating learning that involved higher-order *Cognitive Levels* versus only 23.2% for teachers' lessons earning Level 1 or 2. In juxtaposition, teachers' lessons that earned Level 3 or 4 spent only 37.61% facilitating lower-order *Cognitive Levels* of learning versus 68.37% for teachers' lessons that earned Level 1 or 2. Note that these values do not total 100% for either group because lessons could also earn a Cog Level 0, reflecting that no *Cognitive Level* was expected for administration or other noninstructional activity. The significant differences held true even when the *Cognitive Levels* were further disaggregated to various lower- and higher-order *Cognitive Level*s (see Table 1 and Figure 3). We should note that even when students were not contributing to the explanation, it was quite possible for the cognitive level to achieve a Level 3 or higher. Our measures were based on the intended cognitive level, not necessarily on whether the students actually demonstrated that level. For example, a teacher could explain a concept such as slope in a mathematics class or density in a science class by merely providing information or by stimulating higher-order thinking.

Correlation of Components of Inquiry Facilitated and Cognitive Level of Students

Explore Component of Inquiry. For this portion of the analysis, correlations were sought between the number of five-minute intervals dominated by the Explore and Explain *Components of Inquiry* being facilitated and the number of five-minute intervals dominated by the various *Cognitive Levels* that students were being asked to use during learning (see Table 2). The correlations were considered for all lessons observed, for science lessons only, and for math lessons only.

For all lessons, as the number of intervals spent on Explorations increased, so too did the number of

Table 2
Correlation of the Number of Five-Minute Intervals Spent on Explore and Explain Components of Inquiry and Various Cognitive Levels

Measure (*M*, *SD*)	Inq 2 (Explore) • All (3.92, 3.07) • Science (3.80, 2.98) • Math (2.81, 3.14)	Inq 3 (Explain) • All (4.02, 2.87) • Science (4.13, 2.94) • Math (3.88, 2.80)
Cog. 1 and 2 (lower order)		
All (6.15, 3.58)	−.464***	.345***
Science (5.68, 3.45)	−.411**	.414**
Math (6.81, 3.71)	−.501**	.278
Cog. 3 and above (higher order)		
All (4.36, 3.78)	.539***	−.242*
Science (5.00, 3.81)	.547***	−.242
Math (3.45, 3.58)	.493**	−.279
Cog. 1 (recipient of knowledge)		
All (1.97, 2.02)	.422***	.380***
Science (1.65, 1.90)	−.341**	.290*
Math (2.43, 2.11)	−.481**	.543***

Note. For all observations ($N = 102$), for Science Only ($N = 60$), and for Math Only ($N = 42$).
* $p < .05$, ** $p < .01$, *** $p < .001$.

intervals that students were engaged in learning that involved higher-order *Cognitive Levels*, $r(100) = .539$, $p < .001$. Note that *Cognitive Levels* 3–5 seen on Figure 1 comprise the higher-order category. Further, as the amount of time devoted to student Exploration increased, the amount of time students were engaged in lower-order *Cognitive Levels* decreased, $r(100) = -.464$, $p < .001$. Note that the lower-order *Cognitive Level* measure included *Cognitive Levels* 1 and 2 on Figure 1. The direction and approximate strength of the correlations held true in both cases when considering math lessons and science lessons separately (see Table 2).

Explain Component of Inquiry. The correlation reversed when comparing the number of intervals spent on the Explain portion of the lessons with the *Cognitive Level* engaged in by students. Specifically, the amount of higher *Cognitive Level* involvement among students decreased as the amount of time devoted to Explanation increased, $r(100) = -.242$, $p < .05$. Further, as the time devoted to Explanation increased during the lesson, the students tended to spend more time on learning that involved lower *Cognitive Levels*, $r(100) = .345$, $p < .001$. We further disaggregated the data to determine the relationship between the number of intervals dedicated to Explain and the lowest *Cognitive Level*, receipt of knowledge (Level 1). We found that math lessons had a considerably higher correlation between percent of time spent on Explain and a *Cognitive Level* of 1 ($r(40) = .543$, $p < .001$) than science lessons ($r(58) = .290$, $p < .05$).

Discussion and Conclusion

The goal of the professional development program that involved the 22 teachers was to improve the quantity and quality of inquiry-based instruction being implemented in middle school science and math classrooms. There was not an expectation that teachers would be facilitating instruction via inquiry methods

at all times including during observed lessons. Thus, we saw a large variety of instructional practices and, as expected, because of the large variation in the nature of the lessons, no teacher consistently scored a 3 or a 4 for the *Order of Instruction*. This allowed us to see how teachers facilitate student learning with both inquiry-based and non-inquiry-based strategies.

The analysis showed that when Noninquiry instructional time was replaced with more time for student Explorations, lower *Cognitive Level* thinking was often replaced with high *Cognitive Level* thinking and learning. This finding was true regardless of grade level (6, 7, or 8), discipline (math or science), or school. Further, the lessons that challenged students to interact with material at a higher *Cognitive Level* devoted nearly 17% more class time, frequently during the middle of the lesson, to student Explorations. Both groups devoted approximately one-third of their class time to Explanation of concepts, ideas, and findings, but the group scoring proficient or above on *Order of Instruction* spent much less time on automation, memorization, and other lower *Cognitive Level* forms of learning.

Although some may expect that as Explain time increases, then so too does the *Cognitive Level* of the students, others may expect that when teachers increase the amount of Exploration time, the *Cognitive Level* involving application also increases. Our data confirm the latter. In fact, we found a larger difference in the higher *Cognitive Level* skills such as verify, justify, develop, and formulate when more time was devoted to student Exploration.

Although most of the correlations found with science teachers also held true with math teachers, we noted one clear distinction. For math teachers, when the time devoted to Explain increased, the amount of time dedicated to the lowest *Cognitive Level*, receipt of knowledge, also increased significantly. This correlation was significant enough to justify about 29% of the variance seen in the lessons of math teachers versus only about 8% of the variance noted in lessons of science teachers. While this is not meant to be an indictment of math teaching, it does suggest that science teachers in our study may be further along the continuum than the math teachers in getting students to examine their work critically. Possibly this is because of a difference in instructional goals where computational fluency, without regard to an understanding of the algorithms used to achieve this fluency and thus does not require higher *Cognitive Level* forms of learning, has a greater importance for mathematics teachers than science teachers. However, regardless of the differences in math and science, whether from a standards or philosophical perspective, it is clear that we are all being asked to increase the depth of learning or *Cognitive Level* undertaken by all our students.

A related hypothesis that would be worth exploring in our current world where standardized tests are the benchmark is whether students who spend more time engaged in higher *Cognitive Levels* perform as well or better on these tests than students who spend more time focused on lower *Cognitive Level* thinking. If this proves to be true, then our findings would suggest that teachers who currently focus student learning on specific facts for standardized tests would be justified in shifting to more profound learning that focuses heavily on the enduring ideas in our disciplines.

Implications

We found, in both science and mathematics, a strong relationship between the *Order of Instruction* that teachers use and the *Cognitive Level* at which students are engaged. When teachers give students an opportunity to Explore the concepts prior to an Explanation, no matter whether the teacher or the students provide the Explanation, the students think more deeply about the content. If reasoning and critical thinking are instructional goals, then these results suggest that teachers should consciously provide opportunities for students to develop the ideas for themselves. In our observations, this did not equate to free discovery time, but rather to guided Exploration time in which students were given parameters by which to Explore the concepts. When the goal is not deeper understanding but rather a focus on lower *Cognitive Level* skills, such as automating a certain procedure, then Exploring first may not be helpful. However, whenever the goal is to push toward deeper understanding, then teachers may be well advised to allow students ample opportunities to develop a plan, observe and collect data, and try to determine the underlying constructs.

We also found that as teachers increase the time devoted to Exploration of concepts, the cognitive level engaged in by their students also increases. In our study, this held true in both mathematics and science classes. Perhaps counterintuitively to some, as teachers increase the time spent on the Explanation of concepts, the *Cognitive Level* of the students decreases. Consequently, when the goal is to help students

achieve deep understanding of concepts, teachers may be advised not only to provide time for Exploration before the concepts are Explained but also to ensure that the time allowed for this Exploration is sufficient, even if it replaces time that may have been planned for Explanation.

Our results are based on a limited sample of middle school teachers with whom we have been working during the year. Our goal was to improve the quantity and quality of the inquiry-based instruction being facilitated. Whether or not our results hold true for other grade levels and in different settings, and for teachers who have not been immersed in inquiry-based instruction, remains to be determined. Nevertheless, when the goal is to Engage students at deeper *Cognitive Levels*, teachers may be well advised to provide adequate time for their students to Explore real-world problems before they or their students Explain the underlying concepts.

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A Mixed-Method Study: Assessing the BAR Model's Impact on Preservice Teachers' Efficacy Beliefs

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This study took place at a mid-sized, Midwestern university located in a mid-sized town. The researchers developed the BAR model to teach mathematics methods both in the classroom and in the field. The preservice teachers took Enochs, Smith, and Huinker's Mathematics Teaching Efficacy Beliefs Instrument (MTEBI) on the first and last day of class. A total of 297 responses were collected from the pre- and posttests, with 280 matching responses, which were then used for data analysis. Mixed methods were used to analyze qualitative and quantitative data. The researchers sought to determine if the specific teaching methods from the BAR model led to positive changes in preservice teacher efficacy beliefs. They also explored if efficacy beliefs changed as a result of field experiences. Preservice teachers' efficacy scores changed positively on every item on the MTEBI. The researchers also determined that there was an increase in preservice teachers' outputs as a result of their field experiences.

Purpose of the Study

"It seems imperative that teacher education programs assess their effectiveness, at least in part, on how well they nurture beliefs that are consistent with the program's philosophy of learning and teaching" (Hart, 2002, p.4). Assessing preservice teachers' efficacy beliefs about teaching also plays an important role in assessing a program's effectiveness. Understanding their beliefs about teaching mathematics can send important messages about the university's mathematics methods program. Because of deliberate choices of methods and instruction with opportunities for practice in field experiences, the authors sought to determine if a positive change in preservice teachers' beliefs about teaching mathematics would occur over the semester that could be related to the course's deliberately chosen methodology. It would be important to determine if there would be a positive paradigm shift in preservice teachers' beliefs, attitudes, and motivation toward teaching mathematics. The data thus gathered by studying their beliefs could provide evidence about the mathematics methods program's effectiveness and could be used to inform practice.

To assess the beliefs of preservice teachers in multiple sections of a mathematics methods course, a twofold approach was taken. First, Enochs, Smith, and Huinker's (2000) Mathematics Teaching Efficacy Beliefs Instrument (MTEBI) was chosen to measure the preservice teachers' efficacy beliefs. It was used as a pre- and posttest to determine if there was a significant difference between preservice teachers' Personal Mathematics Teaching Efficacy, or self-efficacy, and Mathematics Teaching Outcome Expectancy, or outcome expectancy (OE), beliefs (Enochs et al.). It was important to assess their beliefs to see their views of what teachers of mathematics should know and do—OE—and how they viewed themselves as successful future teachers of mathematics—self-efficacy (SE). The MTEBI can quantitatively establish whether a preservice teacher's OE and SE changed following participation in the course. If there were any changes in their efficacy beliefs, the researchers assumed that corresponding evidence to support that quantitative data would be found. Collecting both qualitative and quantitative data would enable the researchers to gain a clearer picture of the course's effectiveness in increasing OE and SE as well as developing the preservice teachers' knowledge, skills, and dispositions to teach mathematics. To understand "the belief structures of teacher candidates is essential to improving their professional preparation and teaching practices" (Pajares, 1992, p. 307). Without an understanding of the preservice teachers' beliefs following a deliberately chosen course methodology, needed program changes might not occur.

Therefore, following participation in the university's one-semester mathematics methods course, both quantitative and qualitative data were gathered from

the preservice teachers. The established, valid, and reliable MTEBI (Enochs et al., 2000) served as the vehicle for gathering quantitative data for measuring the preservice teachers' efficacy beliefs about teaching mathematics. Grades on course assessments were also used. Qualitative data were collected from their journals, blind feedback, and a final exam question.

Research Questions

Did the specific teaching methods used in a mathematics methods course lead to positive changes in preservice teachers' efficacy beliefs about teaching mathematics? Did preservice teachers' efficacy beliefs change as a result of their field experiences? Was the course effective?

Literature Review

SE

A large body of literature examines efficacy expectations and beliefs (Bandura, 1977) as they relate to teaching (Ambrose, Clement, & Phillipp, 2004; Bursal & Paznokas, 2006; Enochs & Jesunathadas, 2009; Enochs et al., 2000; Gibson & Dembo, 1984; Hart, 2002; Pajares, 1992, 2001). Expectancy beliefs come from the preservice teachers' own beliefs about their capability to teach mathematics (Pajares, 2001). Preservice teachers also hold outcome beliefs about what they think should happen (Bandura) in a classroom.

Bandura's (1977) SE and behavioral change theoretical framework, which relates individual beliefs to behavioral change, posits that people believe that "a given behavior will lead to certain outcomes" (p. 193). He calls this OE. Furthermore, he states that the individual also holds a belief regarding his or her own ability to successfully execute the specific behavior. Bandura calls this efficacy expectation or SE. "People process, weigh, and integrate diverse sources of information concerning their capability" (p. 212), actions that can in turn lead to an increase (or decrease) in their personal SE.

Performance accomplishments, vicarious experiences through modeling, and feedback play a key role in this theoretical framework (Bandura, 1977). Expectations and beliefs form in part from experience and feedback (Bandura; Pajares, 2001). Pajares stated that "messages people send and receive play an important role in creating the beliefs that they develop" (p. 28). Positive messages (Pajares, 2001) may be related to the personal successes that raise efficacy expectations (Bandura, p. 195). Bandura notes, "Independent performance, if well executed, produces success experiences, which further reinforce expectations of self-competency" (p. 202). Because beliefs underlie behavior, they may then affect a person's performance. These expectations and beliefs form in part from one's experiences and in part from feedback from others (Bandura; Pajares, 2001). Successful experiences can contribute to positive SE beliefs. Furthermore, even the effects of a few negative experiences on a person's efficacy beliefs can be diminished when a strong sense of SE has been established (Bandura).

Performance requirements, therefore, must be well defined to develop and support a strong sense of SE (Bandura, 1977, p. 203). Subjects must clearly understand what is required to successfully complete their tasks. Additionally, they must understand "what kind of behavior will be required and the circumstances in which they will be asked to perform them" (p. 204). For, as Pajares (1992) notes, preservice teachers bring with them outcome expectancies based on their prior experiences and beliefs about teaching gained from many years in a classroom. The preservice teacher may hold some unrealistic expectations. Therefore, by creating specific performance tasks and experiential learning opportunities, the chances for changes in SE for preservice teachers are maximized.

Preservice Teacher Confidence

It has been reported that preservice teachers often lack the confidence to teach mathematics and that these attitudes influence their teaching practices (Brand & Wilkins, 2007; Liang & Richardson, 2009). Bursal and Paznokas (2006) maintain that math anxiety among elementary preservice teachers appears to be a major problem. Furthermore, they concluded that of all undergraduate university students, the group with the greatest degree of math anxiety was the elementary education majors (Bursal & Paznokas). Preservice teacher SE beliefs can have a profound effect in the elementary classroom and can influence classroom behavior (Pajares, 2001).

Methodology

Participants

This study took place at a mid-sized, Midwestern university located in a mid-sized town. Participants included predominantly traditional, white, female

preservice teachers. Most of them were either juniors or seniors in one of six teacher licensure programs. The licensure programs that required a mathematics methods course included (1) birth through grade 6; (2) K–6 with middle-level (grades 5–8) licensure (mathematics, social studies, science, or communication arts); and (3) special education (developmental disabilities and learning disabilities).

Instrument

After obtaining permission from the Institutional Review Board to proceed with the project, a pilot test was run in fall 2007 using all three sections of the mathematics methods course to ensure that MTEBI data were being effectively and anonymously collected. Using the online capabilities of the university's Assessment and Institutional Research (AIR) department, pilot-test data were received and scored according to the five-point Likert scaled MTEBI specifications (Enochs et al., 2000). AIR matched the preservice teachers' pseudo pre- and postassessment identification numbers to eliminate any known or unknown risks to participants in this study and to reduce any limiting results from using a self-reporting survey. As a consequence of the pilot study, a modification was made to the identification code system. This made it easier for the preservice teachers to recall their specific identification code between pre- and posttests. The instrument uses the five-point Likert scale. For tabulation purposes, strongly agree was converted to 5, agree to 4, uncertain to 3, disagree to 2, and strongly disagree to 1.

The actual study used mixed methods (Creswell & Tashakkori, 2007) to analyze the qualitative and quantitative data collected in the spring and fall of 2008. Descriptive statistics, analysis of variance (ANOVA), and coding were incorporated into this study to test the research questions. A descriptive open coding approach was used to find the categorical text from the preservice teacher answers to two open-ended questions. First, an open-ended question from the final exam was: "What was the most important thing you learned from this class?" A second open-ended response came from the blind feedback evaluation given at the end of the course and consisted of a response to the prompt "strengths of the course." Then, counting coding was used to see how often categorical responses occurred (Miles & Huberman, 1994).

Using the AIR portal, the education majors enrolled in Mathematics for Elementary Teachers took the MTEBI (Enochs et al., 2000) on the first and last days of class. A total of 297 responses were collected from the pre- and posttests, with 280 matching responses, which were then used for data analysis.

The MTEBI quantitative data were retrieved by the researchers from AIR following the conclusion of the fall 2008 semester. Preservice teachers' grades from (a) standards-based assignment (Standards); (b) synthesis paper of best practices to create a personal vision of teaching mathematics (Synthesis); (c) small group class lesson (Class Lesson); (d) subjective assessment of participation, attendance, and other similar criteria (Subjective); (e) final exam grade (Final Exam); and (f) final grade for the course (Final Grade) provided additional quantitative data. Supporting evidence from qualitative data was also gathered to substantiate the findings from the MTEBI analyses. Students' own reflections throughout the course provided important evidence of belief changes. The qualitative data were collected during the semester and came from journals, the final examination, and blind feedback provided on a course evaluation form.

Course Design

In keeping with Bandura's (1977) discussion about the components of successful behavioral change in efficacy beliefs, a specific teaching methodology was developed. Preservice teachers needed to clearly understand what was required in order to be successful both in the university classroom and in field experiences. Performance accomplishments and requirements were therefore specifically designed for both of these circumstances. Vicarious experiences through modeling were also designed to provide preservice teachers with additional ideas and techniques for classroom use. Continuous feedback from the professor and some peer feedback enabled them to reflect on and modify their work. During class and in the public schools, the course's design was intended to increase preservice teacher confidence and to foster positive attitudes toward teaching mathematics (Bursal & Paznokas, 2006).

Each of these means or perspectives was accomplished through a system that the authors call the BAR model: (a) Build knowledge; (b) Act on the knowledge through discussion and/or assignments and feedback; and (c) Reflect on the action and knowledge. This circular model provided coherence in learning and instruction. Feedback along the way allowed preservice teachers to modify or change many of the

assignments or lessons in a continuous improvement process (National Council of Teachers of Mathematics [NCTM], 2000). While building more knowledge and confidence, this feedback also created more action by allowing them to make appropriate changes based on reflection and feedback and required them to further reflect, an action intended to reinforce their learning and confidence, or SE. The BAR model was further grounded in a field-based component of the class (Brown, Morehead, & Smith, 2008; Lowery, 2002; Maxie, 2001; Putnam & Borko, 2000), enabling the preservice teachers to present lessons based on their classroom learning. O'Brian, Stoner, Appel, and House (2007) describe field experiences as authentic contexts. Preservice teachers encounter the real world of teaching in those settings. All components of the BAR model were intended to increase preservice teachers' SE.

The course design clearly delineated requirements and expectations.

> For example, highly efficacious teachers have been found to be more likely to use inquiry and student-centered teaching strategies, while teachers with a low sense of efficacy are more likely to use teacher directed strategies, such as lecture and reading from the text. (Czerniak as cited in Enochs & Jesunathadas, 2009, p. 2)

Both inquiry methods and student-centered teaching activities were foundations in the course. Another expectation of the course was that the preservice teachers behave as effective professionals in the field following scaffolded understanding (Brown et al., 2008) and learning situations. Learning situations were designed to build the preservice teachers' confidence and knowledge about teaching mathematics and to reinforce success. "Behavior is enacted when people not only expect specific behavior to result in desirable outcomes (outcome expectancy), but they also believe in their own ability to perform the behaviors (self-efficacy)" (Enochs et al., 2000). Inquiry and active engagement (Beswick, 2006) by the preservice teachers provided a foundation that increased readiness for teaching experiences in public school classrooms.

Using the BAR model also enabled the preservice teachers to learn a hands-on method of teaching mathematics grounded in: (a) foundational knowledge (Martin & Speer, 2009); (b) active participation (Taylor, 2000); (c) reflection (Brown et al., 2008; Hart, 2002; Soto-Johnson, Iiams, Oberg, & Hoffmeister, 2008); (d) discussion (Brown et al.; Martin & Speer, 2009); and (e) feedback (Bandura, 1977; Chickering & Gamson, 1999; Fernandez, 2005; Liang & Richardson, 2009; Mewborn & Stinson, 2007). This moved teaching away from a direct instruction approach to a more constructivist approach (Beswick, 2006; Lowery, 2002; NCTM, 2000) to teaching mathematics. Also included in the course was a social constructivist or collaborative approach based on the past work of Vygotsky (1978). This was accomplished through multiple means or perspectives (Thomas & Pedersen, 2003).

During the first few weeks of class, the preservice teachers spent time learning the theories and the methodology that underlie the best practices (SciMathMN, 1997) of the discipline's pedagogy. This was achieved through reading, watching videos, discussion, and reflection. It is important for the preservice teachers "to be communicating their mathematical thinking, defending and justifying their arguments, and working with others to construct mathematical knowledge" (Hart, 2002, p. 4). An assessment component included an open-ended group presentation based on best practices and foundational knowledge. A required paper combined preservice teachers' ideas with best practices to create a personal vision of teaching. Repetitive use of best practices in multiple formats led to an automatic integration of best practices (SciMathMN) in teaching.

Once the underpinnings of teaching mathematics using best practices were established, using a hands-on approach to teaching the mathematics lessons embedded in the state standards linked theory to practice (Mewborn & Stinson, 2007). Inquiry training helped the university students learn to use multiple perspectives to reach the diverse needs learners (Darling-Hammond, 2000, p. 17). Active participation and inquiry learning were essential components in the process of engaging the preservice teachers in their learning (Johnson, 2001, p. 395). The preservice teachers learned using a hands-on approach rather than a text-based approach. Each of them was required to purchase a manipulatives kit that included numerous manipulatives and a manual of lesson ideas for using them. A wide variety of other manipulatives was also available for class use to help acquaint the preservice teachers with multiple methods of teaching content through hands-on experiences. These hands-on experiences allowed them to develop a

deeper understanding of mathematical concepts at various grade levels and to be able to teach them. The pattern of the BAR cycle was repeated as they built knowledge about the materials' uses, acted by using this knowledge in lessons and receiving teacher feedback while engaged in the learning activities, and reflected on their new learning to seek new solutions to posed problems.

Simultaneously, lesson planning (Anderson, 2000; Hart, 2002) and its applications were woven into the curriculum. The preservice teachers began to create detailed lesson plans as another part of the foundational knowledge for teaching mathematics.

Preservice teachers first planned and presented a small-group class lesson based on a randomly chosen topic and grade level. Constructive feedback on delivery, flow, appropriateness of activities, strengths, and areas needing improvement was provided by both peers and the professor. The professor additionally critiqued format, content, and the lesson's success at meeting the objectives relevant to the selected standard(s). The professor also gave further feedback about the lesson's actual delivery, i.e., "No, 'you guys,' " or "When at the chalkboard, talk to your students, not the board." Preservice teachers had the opportunity to revise the initial lesson plan based on all feedback. BAR: Build, Act, Reflect—repeat. The revised plan was graded.

The activities presented to the preservice teachers throughout the course employed diverse materials, strategies, and best practices (Anderson, 2000; NCTM, 2000; SciMathMN, 1997). This process helped prepare them for their professor-supervised field experiences (Brabeck & Shirley, 2003; Brown et al., 2008; Doster & Poulter, 2008; Graham & Fennell, 2001; Hart, 2002; McGlamery & Harrington, 2007; Putnam & Borko, 2000) with the public school teaching partners (Brabeck & Shirley; Linek, Fleener, Fazio, Raine, & Klakamp, 2003). The lesson topics were selected by the classroom teachers and the professor that were based on state standards and were intended to help prepare the school-aged children for the high-stakes statewide mathematics tests in the spring.

In two of the three mathematics methods sections, preservice teachers worked either individually or with a partner to prepare school lessons in a station format. The children rotated through a different station on each of five different days. In the third section, preservice teachers individually prepared a series of different lessons for each of the eight days in the school; they then taught this series to the same children each time. Both groups received feedback from the professor, and the preservice teachers reflected on the actual teaching experience in the required reflection journal (McGlamery & Harrington, 2007). Both types of sessions were structured to increase the comfort level (Bursal & Paznokas, 2006) of the preservice teachers by having them teach to small groups of children rather than a whole class.

Modifications were required for the five-session group's lesson plans. After the second delivery of the lesson in this group, the preservice teachers modified the lesson to employ a different means of teaching the same content. The preservice teachers kept only a few successful components of the original plan, as the goal was to reinforce that there are multiple means of teaching the same content to children. The preservice teachers who taught six different lessons in their eight days of experience ensured that varied and active methods of teaching were included in every lesson. These preservice teachers also developed an assessment covering all material they taught, and a reteaching day following the assessment day. The reteaching day enabled this group of preservice teachers to create modifications from the past lessons to reteach the concepts with which the children struggled. The required reflection journals helped inform all the preservice teachers about their instruction (McGlamery & Harrington, 2007). The BAR cycle continued.

The professor attended all field sessions and circulated among the children and their preservice teachers. Mewborn and Stinson (2007, p. 1483) state that the "university supervisor might intervene in a lesson to ask a question that better reveals student thinking, to offer a management suggestion, or to make a connection to the previous day's lesson." This was a given in all classes. On-the-spot or after-class feedback also helped the preservice teachers in their reflection on the day's lesson. As noted by Putnam and Borko (2000), combining university course experiences with coordinated classroom experiences allows preservice teachers to "learn new ideas and practices, as well as to reflect and receive feedback on their teaching" (p. 7). Furthermore, this "intertwining of theory and practice" (Mewborn & Stinson, p. 1464) provided the preservice teachers with the opportunity to fully interact with the BAR model while in the field.

Preservice teachers had multiple opportunities to implement their plans with real children rather than only with peers in a classroom. Until that time,

children's differences remained abstract to many of the preservice teachers. By structuring small-group teaching situations, the preservice teachers actually experienced how different learning and ability are even within a very small group of children. "No one way to approach mathematics teaching will work with every student in all situations" (Graham & Fennell, 2001). Experience in teaching small numbers of children was intended to increase the comfort level of the preservice teachers during their first exposure to teaching content lessons to K–8 children. It also provided the professor with the opportunity to address meeting children's needs through curriculum differentiation. Differentiating curriculum enhanced the classroom experience for the children regardless of ability, ethnicity, cultural background, or gender. It allowed the preservice teachers to meet individual and group needs by varying content, and process and product were varied with respectful tasks for the learners (Tomlinson & Allan, 2000).

At the same time, the professor also addressed exceptionalities, such as gifted students or children with special needs, during class periods. The preservice teachers needed strategies to provide for children's differences. Allowing preservice teachers to experience these differences in small groups enabled them to seek solutions and modify lessons (Anderson, 2000) in a less threatening situation (Bursal & Paznokas, 2006) prior to encountering children's differences in a whole-class setting. Experience and the opportunity to build, act, reflect, and receive feedback helped prepare the preservice teachers to become capable teachers. "The practice and repetition is useful in gaining skills and developing a sense of how best to structure and prepare a lesson" (McGlamery & Harrington, 2007). Multiple lesson preparations and delivery gave the preservice teachers this experience.

In addition to field experiences, the preservice teachers designed a standards-based unit (Anderson, 2000; Taylor, 2000). Writing the unit demonstrated the preservice teachers' ability to arrange a series of cohesive standards-based lesson plans that smoothly transitioned from one to the next. Designing assessments, both formal and informal, also played an integral role in the unit. In accordance with the BAR model, the preservice teachers visited the professor, if desired, to receive specific feedback on the unit design. This component allowed preservice teachers to make use of the feedback and make revisions accordingly (Fernandez, 2005). This was another means to help ensure their success.

The deliberate design of the course was intended to enable preservice teachers to prepare and present well-designed, hands-on lessons. The learner-centered approach to teaching mathematics was used so that active participants were engaged in deep, enduring, and enjoyable learning that would enable the preservice teachers to transfer the experience to contexts beyond the university classroom (Walczyk & Ramsey, 2003).

Results

Quantitative Data

Quantitative data were gathered from the five-point Likert scaled MTEBI and preservice teachers' grades. The MTEBI provided both the preservice teachers' mathematics teaching OE and their personal mathematics teaching SE scores. The OE examined the preservice teachers' beliefs about teaching mathematics. The SE examined the preservice teachers' beliefs about their own teaching. The descriptive statistics for the MTEBI items (see Table 1) included in the output were the number of subjects (*N*), the mean, and the standard deviation (*SD*). In this table only matched scores were used for evaluation. The *N* in the pre- and posttests differed because not all students took either the pre- or the posttest because of absence. In every instance, the mean increased between the pre- and the posttest, while the standard deviation decreased in most cases between pre- and posttests.

The Cronbach's alpha reliability test was conducted to test the internal consistency for the two subscales on the two-item MTEBI: SE and OE. Cronbach's alpha coefficients of .86 for the SE scale and .76 for the OE scale were obtained, which were similar to results obtained in the original MTEBI study (Enochs et al., 2000). The sample size had sufficient power to detect any significant effects based on the medium level (.5) of the anticipated Cohen's *d* (Cohen, 1992).

Table 2 provided an ANOVA for all of the MTEBI survey items. While Table 1 indicated a positive change in all items on the MTEBI, the results shown in Table 2 indicated that significant differences were found for 15 of 21 items between pre- and posttests. There were significant differences for 4 out of 8 items measuring OE, while 11 of 13 items showed significant differences for SE.

Table 3 illustrated the means of each of the class grades from the three different class sections.

Table 1
Descriptive Statistics from the MTEBI Survey Data

Abbreviated MTEBI Survey Items	Pre			Post		
	N	Mean	*SD*	*N*	Mean	*SD*
1. Teacher exerted effort	157	3.71	.88	140	3.98	.73
2. Find better ways to teach	157	4.45	.58	138	4.68	.50
3. Will not teach math well	156	3.67	.90	140	3.82	.90
4. Effective teaching approach	157	4.00	.62	140	4.12	.58
5. Teach concepts effectively	157	2.72	.74	140	4.11	.56
6. Ineffective monitoring activities	156	3.85	.72	139	4.15	.77
7. Underachieve ineffective teaching	157	3.18	.84	137	3.36	.85
8. Teach math ineffectively	157	4.04	.72	139	4.28	.79
9. Good teaching	156	3.81	.66	139	4.01	.60
10. Low achievers	155	3.84	.65	139	3.89	.66
11. Understand enough to teach	157	3.39	.86	140	4.26	.56
12. Teacher responsible	157	3.52	.79	140	3.79	.68
13. Achivement related to effectiveness	157	3.52	.80	140	3.87	.70
14. Parents comment	155	3.79	.71	138	3.93	.60
15. Manipulatives	157	3.74	.82	139	4.29	.80
16. Answer students' questions	157	3.75	.64	140	4.21	.58
17. Skills to teach	157	2.69	1.04	139	3.65	.89
18. Will not invite principal	156	3.40	.94	139	3.65	.98
19. Be at a loss	156	3.83	.65	140	3.92	.76
20. Welcome student questions	157	4.39	.64	139	4.55	.61
21. Turn students on to math	157	3.01	.86	140	4.00	.61

Note. Abbreviated descriptors based on MTEBI survey items (OE: 1, 4, 7, 9, 10, 12, 13, and 14; SE: 2, 3, 5, 6, 8, 11, 15, 16, 17, 18, 19, 20, and 21).

Table 4 indicated that there were significant differences in preservice teachers' outcomes between the different class sections on (a) the class lesson project, $F(2, 154) = 4.366$, $p = .01$, partial eta$^2 = .05$; (b) the subjective, $F(2, 155) = 4.97$, $p = .08$, partial eta$^2 = .06$; and (c) the final exam scores, $F(2, 155) = 8.35$, $p = .00$, partial eta$^2 = .10$. The assumptions of independent observations, homogeneity of variances, and normal distributions of the dependent variable for each group were checked.

Table 5 provided descriptive statistics to show the means of each grade by the number of field experience visits (five visits versus eight visits). Table 6 showed that there were significant differences in preservice teachers' outcomes (a) on the class lesson grade among different class sections, $F(1, 151) = 5.87$, $p = .02$ partial eta$^2 = .04$; (b) in subjective, $F(1, 155) = 8.78$, $p = .04$, partial eta$^2 = .05$; and (c) in final exam scores, $F(1, 156) = 9.29$, $p = .00$, partial eta$^2 = .06$. No other significant differences were found by comparing

Table 2
MTEBI Survey Response ANOVA Between Pre- and Posttest

Source		*df*	MS	*F*	Sig.
Teacher exerted effort	Between groups	1	5.46	8.24*	.00
	Within groups	295	.66		
	Total	296			
Find better ways to teach	Between groups	1	3.85	12.98*	.00
	Within groups	293	.30		
	Total	294			
Will not teach math well	Between groups	1	1.77	2.17	.14
	Within groups	294	.81		
	Total	295			
Effective teaching approach	Between groups	1	1.09	3.01	.08
	Within groups	295	.36		
	Total	296			
Teach concepts effectively	Between groups	1	143.94	327.00*	.00
	Within groups	295	.44		
	Total	296			
Ineffective monitoring activities	Between groups	1	6.55	11.89*	.00
	Within groups	293	.55		
	Total	294			
Underachieve ineffective teaching	Between groups	1	2.55	3.60	.06
	Within groups	292	.71		
	Total	293			
Teach math ineffectively	Between groups	1	4.11	7.24*	.01
	Within groups	294	.57		
	Total	295			
Good teaching	Between groups	1	2.93	7.31*	.01
	Within groups	293	.40		
	Total	294			
Low achievers	Between groups	1	.21	.49	.48
	Within groups	292	.43		
	Total	293			
Understand enough to teach	Between groups	1	55.02	102.56*	.00
	Within groups	295	.54		
	Total	296			

Table 2
Continued

Source		*df*	MS	*F*	Sig.
Teacher responsible	Between groups	1	5.68	10.32*	.00
	Within groups	295	.55		
	Total	296			
Achievement related to effectiveness	Between groups	1	9.35	16.53*	.00
	Within groups	295	.57		
	Total	296			
Parents comment	Between groups	1	1.44	3.29	.07
	Within groups	291	.44		
	Total	292			
Manipulatives	Between groups	1	22.21	33.88*	.00
	Within groups	294	.66		
	Total	295			
Answer students' questions	Between groups	1	15.36	41.07*	.00
	Within groups	295	.37		
	Total	296			
Skills to teach	Between groups	1	66.99	70.58*	.00
	Within groups	294	.95		
	Total	295			
Will not invite principal	Between groups	1	4.63	5.08*	.03
	Within groups	293	.91		
	Total	294			
Be at a loss	Between groups	1	.57	1.16	.28
	Within groups	294	.50		
	Total	295			
Welcome student questions	Between groups	1	1.85	4.77*	.03
	Within groups	294	.39		
	Total	295			
Turn students on to math	Between groups	1	72.13	126.68*	.00
	Within groups	295	.57		
	Total	296			

Note. Based on MTEBI survey items (Enochs et al., 2000).
* $p < .05$.

Table 3
Descriptive Statistics of Class Projects by Different Class Sections (1, 2, 3)

Class Assessments	Sections	*N*	*M*	*SD*
Standards	1	55	4.10	.41
	2	43	3.88	.70
	3	55	4.09	.37
	Total	153	4.03	.50
Synthesis	1	56	4.23	.21
	2	44	4.29	.20
	3	54	4.32	.23
	Total	154	4.28	.22
Class lesson	1	56	4.19	.33
	2	46	3.97	.66
	3	55	4.20	.28
	Total	157	4.13	.45
Subjective	1	55	4.36	.11
	2	46	4.30	.16
	3	57	4.38	.11
	Total	158	4.35	.13
Final exam	1	55	4.30	.19
	2	46	4.38	.13
	3	57	4.42	.15
	Total	158	4.37	.17
Final grade	1	56	4.14	.60
	2	46	4.25	.15
	3	57	4.25	.19
	Total	159	4.21	.38

classes with different numbers of field experience visits.

Qualitative Data

A variety of qualitative data was retrieved from the preservice teachers, including comments from their final examinations, reflection journals, and blind feedback from the course evaluation.

Evidence from the final exam question "What was the most important thing you learned from this class?" was specifically analyzed for themes or trends to support the MTEBI data. Note that participant bias was possible because of self-report on the final exam. From this analysis, several obvious themes emerged: (a) teaching in the public schools; (b) learning how to use manipulatives to teach mathematics; (c) learning multiple teaching strategies; (d) using active engagement and collaborative strategies; (e) gaining personal confidence to teach; and (f) learning best practices. One additional category emerged and was labeled: (g) other. This category included items such as writing lesson plans, designing a unit, or other general ideas (see Table 7). Teaching in the public schools tied with learning to use manipulatives as the two most significant responses to this question. Preservice teachers also indicated that their confidence levels rose during this course. One other area that received considerable attention was learning about the best practices of teaching mathematics.

Blind feedback (see Table 8) obtained from the anonymous end-of-course evaluation form paralleled the findings previously indicated from the final exam question. In response to the open-ended "strengths of the class" question, 87 responses discussed the field experiences. Another 71 responses indicated that learning to use the manipulatives from the class was invaluable. Forty-four responses included things such as learning to write lesson plans, the way the course was conducted, and the use of best practices.

Discussion and Conclusion

The preservice teachers' efficacy scores show positive changes on every item on the MTEBI (see Tables 1 and 2). The data suggest that the preservice teachers increased their OE and SE as result of this class. Their descriptor choices changed from "uncertain" and "agree" to "agree" and "strongly agree," particularly for the items about effective teaching of mathematics concepts and understanding enough to teach them. Similar results also indicate a rise in their SE, reflecting their acquisition of the necessary skills to teach and the ability to turn students on to mathematics.

Items in Table 2 indicate that 15 of 21 items show significant changes. Of those, only 2 of the 13 items from the SE scoring showed no change between the pre- and the posttest. For preservice teachers' OE, four out of eight items showed no significant change. The fact that only two items were not significant for SE appears to be related to the fact that one question

Table 4
One-Way ANOVA for Class Project Outcomes by Different Class Section

Source		*df*	MS	*F*	*P*	eta^2
Standards	Between groups	2	.7	2.92	.06	.04
	Within groups	150	.25			
	Total	152				
Synthesis	Between groups	2	.10	2.19	.12	.03
	Within groups	151	.05			
	Total	153				
Class lesson	Between groups	2	.84	4.37*	.01	.05
	Within groups	154	.19			
	Total	156				
Subjective	Between groups	2	.08	4.97*	.01	.06
	Within groups	155	.02			
	Total	157				
Final exam	Between groups	2	.21	8.35*	.00	.1
	Within groups	155	.03			
	Total	157				
Final grade	Between groups	2	.21	1.47	.23	.02
	Within groups	156	.15			
	Total	158				

* $p < .05$.

asked preservice teachers to indicate whether they would teach mathematics as effectively as other subjects. Because of the wide variety of education majors in the class, it appears that nonmathematics majors believe they can teach mathematics, but they believe they can teach their own major subject better. The other item under SE that shows no significant difference may be related to the fact that most of preservice teachers initially agreed that they would not be at a loss to help students understand better. Onc OE question that shows no significant difference between pre- and posttests is likely because the students already believed that grade improvement is a result of teaching. They also initially agree that underachievers might progress in a classroom with extra teacher attention, and they maintain this belief. They also agree on both the pre- and the posttest that teachers influence student interest in mathematics. The lack of significant changes on these items relates to the preservice teachers' initial confidence about these issues.

Results also show that there are possible links between efficacy beliefs and the preservice teachers' outputs, or grades, as a rcsult of their field experiences (see Tables 5 and 6). Data from assignments, the final exam, a subjective grade, and their final grade indicate this. The data correlate the amount of times the preservice teachers were in the field: either five hours or eight hours (see Table 3) with grades. Before the field experiences, the classes that were to receive eight hours of field experience had lower assessment grades than those with five hours. Following the field experiences, the final exam scores and the final grades are similar in all three sections. All three sections also show a significant difference in their subjective grades (see Table 6). The mean scores for the eight-hour section's grades are improved by approximately 6% over

Table 5
Descriptive Statistics of Class Projects by Field Experience Visitation Number (Five Times Versus Eight Times)

Class Assessments	Visitation Number	*N*	*M*	*SD*
Standards	5 (Sections 1 and 3)	110	4.1	.39
	8 (Section 2)	43	3.88	.70
	Total	153	4.03	.50
Synthesis	5 (Sections 1 and 3)	110	4.28	.22
	8 (Section 2)	44	4.29	.20
	Total	154	4.28	.22
Class lesson	5 (Sections 1 and 3)	111	4.2	.31
	8 (Section 2)	46	3.97	.66
	Total	157	4.13	.45
Subjective	5 (Sections 1 and 3)	112	4.37	.11
	8 (Section 2)	46	4.30	.16
	Total	158	4.35	.13
Final exam	5 (Sections 1 and 3)	112	4.36	.18
	8 (Section 2)	46	4.38	.13
	Total	158	4.37	.17
Final grade	5 (Sections 1 and 3)	113	4.2	.44
	8 (Section 2)	46	4.25	.15
	Total	159	4.21	.38

their prefield experience grades, while the five-hour sections' grades are improved by approximately 2%. Field experiences thus have a positive impact on preservice teachers' grades as well as on their SE.

Teaching in the public schools is one of the most important learning experiences for the preservice teachers (see Tables 7 and 8). One preservice teacher (Student A, personal communication, May 8, 2008) said, "I really enjoyed this experience at [the elementary school]. I feel much more prepared to teach math after having this opportunity." Practicing in a safe environment with a small group benefited the preservice teachers. Tellingly, Student B (personal communication, May 6, 2008) acknowledges that she had questioned her desire to teach but that "[o]nce I finally got to go out into the classroom and teach my own lesson plans, I got such a rush from it, and I absolutely loved it. I am 110% sure that this is what I want to do with the rest of my life." Classroom learning and supervised field experiences translate into making a difference. Sixty preservice teacher responses support this.

Using manipulatives to teach and learn mathematics also struck a deep chord with the preservice teachers, as another 60 of them agree that this is their most important learning experience. Said Student C (personal communication, May 7, 2008), "I'm glad I brought along the die [*sic*]—they got pretty excited about something so simple. It just reinforces the idea that manipulatives are a must! I am going to try to incorporate as many hands-on experiences as possible." This comes as a surprise to the preservice teachers. Others say that during the class they finally understand one or more of the concepts of mathematics that they previously "did not get." Also, they saw

Table 6
One-Way ANOVA for Class Project Outcomes by Field Experience Visitation Number

Projects		*df*	MS	*F*	*p*	eta^2
Standards	Between groups	1	1.44	5.87*	.02	.04
	Within groups	151	.24			
	Total	152				
Synthesis	Between groups	1	.01	.24	.63	.00
	Within groups	152	.05			
	Total	153				
Class lesson	Between groups	1	1.69	8.78*	.00	.05
	Within groups	155	.19			
	Total	156				
Subjective	Between groups	1	.14	9.29*	.00	.06
	Within groups	156	.02			
	Total	157				
Final exam	Between groups	1	.01	.52	.47	.00
	Within groups	156	.03			
	Total	157				
Final grade	Between groups	1	.10	.67	.41	.00
	Within groups	157	.15			
	Total	158				

* $p < .05$.

the benefit of using the manipulatives to teach mathematical concepts. One future teacher said (Student D, personal communication, December 17, 2008),

> Before taking this class, I still thought that math was all about completing the assigned worksheet for the day. I learned there are many different ways to incorporate concrete materials into a lesson as basic as addition to help students gain a better understanding of the concept.

The word "confidence" shows up numerous times in the blind evaluation. Note that the professor deliberately did not say the words "confidence" or "confident" during class. Mentions of gaining confidence come from the preservice teachers' own reflections rather than from a notion suggested by the professor. One preservice teacher states (Student E, personal communication, December 18, 2008), "Math is definitely not my strongest subject. However, this class helped me boost my own confidence in teaching by showing me how to teach math ideas and concepts in many different ways." The BAR method fully intends to scaffold preservice teacher learning to ultimately allow the preservice teachers to gain confidence as mathematics teachers. "Elimination of 'math anxiety' opened doors into my own mind," says Student F (personal communication, December 16, 2008).

During fall 2008, one student repeated the course because she had failed it in spring 2008. The reason she failed was simply that she did not show up for the field experiences. She was afraid to try to teach mathematics. Follow-up discussions were held about her chosen career, but she still insisted that she wanted to be a teacher in spite of her fear of mathematics. She repeated the course in the fall and received an A for

Table 7
Students' Final Exam Self-Reported Most Important Learning from the Class

Class/Section	A	B	C	D	E	F	G	Total
SP08-01	9	13	3	3	3	4	6	41
SP08-02	7	12	4	0	1	1	5	30
SP08-03	10	4	0	0	3	3	3	28
F8-01	9	11	2	4	9	6	5	46
F8-02	15	5	7	1	5	10	2	45
F8-03	10	15	2	1	5	3	2	38
Total	60	60	18	9	26	27	23	223

A = teaching lessons in the schools; B = learning and teaching by using manipulatives; C = learning multiple teaching strategies; D = using active engagement and/or collaborative techniques; E = gaining personal confidence to teach mathematics; F = learning best practices; G = other.

Table 8
Students' Self-Reported Strengths of the Class—On Blind Feedback Instrument

Class/Section	A	B	C	D	E	Total
SP08-01	14	10	2	4	2	32
SP08-02	22	5	3	2	1	33
SP08-03	21	14	4	1	3	43
F8-01	13	20	2	0	2	37
F8-02	9	7	4	1	3	24
F8-03	8	15	6	2	2	33
Total	87	71	21	10	13	202

A = field experiences; B = learning and teaching by using manipulatives; C = unit/lesson plans; D = best practices; E = other.

excellent work and for her field experiences. When responding to the most important learning experience question, Student G states (personal communication, December 17, 2008),

> I feel as though my personal gain from this class was a greater sense of confidence. Math was never my strong subject in school, and I was very apprehensive to teach young students. I was worried that I would not be able to teach something that I myself had struggled with when I was learning it. Teaching at [the elementary school] really helped because it made me realize that I could teach math, if I wanted to. It also made me feel more confident about my own skills as a teacher.

This is a strong testament to the fact that practicing with a small group in a supportive, professor-supervised situation allows her to experience success and increase her own SE.

Within the realm of best practices are other strategies and techniques that served the preservice teachers well. One other area that received considerable attention was learning about the best practices of teaching mathematics.

Using the circular repetitions of the BAR model in this study provides coherence in learning and instruction. The BAR model helps students build a knowledge base through action in both the university classroom and the elementary schools. Reflection on feedback reinforces learning and preservice teachers' confidence or SE. From the evidence of the results reported above, the components of the BAR model led to an increase in preservice teachers' SE.

Examining the preservice teachers' reflections sheds a great deal of light on the link between the qualitative and quantitative results of this study. The preservice teachers feel empowered, show a gain in confidence, and believe themselves to be successful teachers of mathematics. As Student H (personal communication, December 17, 2008) notes,

> I never really considered myself good at math and did not really think teaching it would be one of my strengths. After learning many things in this course and going out to use what I learned in the classroom, I found out that I can teach math, and I will be good at it. . . . I can be a great math teacher. I have strategies that I can use to effectively teach the concepts of math and make it enjoyable to my students.

There is a change in student beliefs. An increase of positive SE is repeatedly shown. Providing concrete evidence of student belief changes and teaching practice improvement serves to show the effectiveness of the BAR model. Previously anxious preservice teachers have found a new level of confidence about their own abilities to teach mathematics. They

demonstrate teacher effectiveness while teaching lessons in the classroom settings. They perform well on class assignments. The course's effectiveness is well documented.

This model will serve other education programs through the system of the BAR model. As consequences of this approach, preservice teachers' actual teaching in their own classroom will benefit from the BAR model's connection between theory and practice. This will give them an opportunity to provide a leadership in their own classroom and potentially to others. Usually, the first year of teaching is the most challenging, but BAR will give the preservice teachers an opportunity to strengthen their teaching experience connecting theory to practice prior to their first year out in the real world of teaching. They will come to teaching with a higher level of confidence and will teach with concrete context knowledge. The elements of BAR will give them concrete process of teaching to make them well prepared to teach mathematics. The BAR model will be a useful tool for preservice teacher educators to prepare our preservice teachers for teaching mathematics.

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Data Analysis and Statistics in Middle Grades: An Analysis of Content Standards

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The purpose of the study reported herein was to identify the important aspects of statistical knowledge that students in the middle school grades in United States are expected to learn as well as what the teachers are expected to teach. A systematic study of 49 states standards and one set of national standards was used to identify these important aspects, and to measure the degree of emphasis or importance suggested for the content. Results show that state and national standards differ greatly in their expectations of what topics in data analysis and statistics students and teachers should master. There is also a large variation in the degree of emphasis given to the content. The majority of the standards analyzed suggest giving greater emphasis to the selection and proper use of graphical data representation and measures of center.

As statistics becomes more prevalent in the K–12 school mathematics curriculum and nearly ubiquitous in everyday discourse, the need for a statistically literate population has become imperative. Implementation of K–12 school mathematics curriculum aligned with reform movements has challenged teachers and teacher educators in many ways. New content, such as statistics, is one of these challenges. Many experts agree that teachers' own deep and substantial knowledge of mathematics content is a key factor in providing quality mathematics education (Ball, Lubienski, & Mewborn, 2001; National Research Council [NRC], 2001). The inclusion of statistics topics across the school curriculum from kindergarten to grade 12, as suggested by *Principles and Standards for School Mathematics* (National Council of Teachers of Mathematics [NCTM], 2000), provides the rationale to investigate what the fundamental concepts students are expected to learn and what teachers need to know. Recently, the Center for the Study of Mathematics Curriculum (CSMC) has investigated this issue for other content areas such as number and operations, algebra, and reasoning (Reys & Lappan, 2007).

The purpose of this study is to address a question fundamental to the teaching and learning data analysis and statistics in the middle grades: What are the important concepts (or big ideas) students and teachers are expected to know? More specifically, what are the important statistical *content topics* taught in middle school? What are the *cognitive demands* (such as memorize, perform procedures, and solve nonroutine problems) that are related to the content?

Before addressing these questions, a historical prospective of the inclusion of statistical content in the school curriculum is presented in the first section of the paper. A systematic review of content standards and their analysis follows. The paper ends with a discussion of implications for teacher preparation.

Statistical Content in the School Curriculum

The introduction of statistics in school mathematics started at the beginning of the 20th century when the Mathematical Association of America (MAA) appointed the National Committee on Mathematical Requirements in 1916. The committee's final report published in 1923 advocated a general mathematics program for grades 7–12, which included graphs and descriptive statistics (Jones, 1970). In particular, the report suggested the study of measures of center as part of either 10th- or 11th-grade courses.

In the mid-'40s, the secondary schools' college preparatory program based their objectives on a report in which the key word to describe the role of mathematics was "appreciation." The report suggested a course in the senior year that comprised a survey of elementary trigonometry, statistics, and precision of measurements and use of graphs. At the same time, the Commission on Post-War Plans of the NCTM reports suggested statistics as one of the 29 key concepts for junior high school.

Even though clear efforts were undertaken to improve the secondary program, a survey conducted by the Educational Testing Service in 1954 indicated that there were problems. In 1955 the Committee on Examinations of the College Entrance Examination Board appointed a commission formed by college mathematicians, high school teachers, and college teachers of mathematics education. The suggestions of

the commission, published in 1959, were minor with respect to change in content but emphasized important changes in instruction and teaching. As in the previous reports, the commission recommended descriptive statistics in grade 9 and the study of probability with statistical application as an optional course in grade 12. For the first time attention was paid to the teaching of probability and statistics.

Suggestions about including the study of statistics and probability in school mathematics in the late '50s were reflected by the inclusion of the content in curriculum materials developed by the School Mathematics Study Group. The study group created a book for a one-semester course on probability and statistics for 12th grade.

By the mid-1960s the secondary school program was well established with many exemplary experimental programs. As a result, textbooks, new materials, and the reform efforts turned their attention toward the elementary school level. In the summer of 1962, mathematicians and representatives of the National Science Foundation met in Cambridge to discuss the state of mathematics in elementary and secondary schools. The following year they published *Goals for School Mathematics*; one of the key ideas was that "some 'feeling' for probability and statistics was considered important for all students" (Jones, 1970, p. 291).

In the late '70s the National Council of Supervisors of Mathematics (1977), an organization composed of mathematics leaders at district, state, and university levels, published its *Position Paper on Basic Mathematical Skills*, which defined "basic skills" as including not only computation but also estimation, geometry, problem solving, computer literacy, and statistics and probability. More specifically, the report suggests that students should know how to read, interpret, and construct tables, charts, and graphs. This report, and others, prompted the NCTM to appoint a committee to develop recommendations for school mathematics for the '80s. The product, *An Agenda for Action*, was one of the earliest position statements from the NCTM (1980) and a definitive step toward reform. It set problem solving as the curricular focus and recommended that the definition of "basic skills" be broadened to include such mathematical skills as estimation and logical reasoning, and promoted the use of calculators and computers in the classroom at all grade levels. Another publication that awakened the general public to crisis in the United States was *A Nation at Risk*. Commissioned by the National Commission for Excellence in Education (1983), this report lays out the critical status of students' performance and gives recommendations about content, expectations, time, and teaching. In particular, the report suggests that the teaching of mathematics in high school—whether the students are college bound or not—should equip graduates to understand elementary probability and statistics among others.

In 1986, the Board of Directors of the NCTM established a Commission on Standards for School Mathematics to help improve the quality of school mathematics. The commission published in 1989 *Curriculum and Evaluation Standards for School Mathematics* (NCTM, 1989) and later *Principles and Standards for School Mathematics* (NCTM, 2000), and placed, for the first time, statistics and probability on an equal footing with numeration, measurement, algebra, and geometry in their importance in kindergarten through grade 12. These standards suggest that instructional programs should enable all students to formulate questions that can be addressed with data; collect, organize, and display relevant data; select and use appropriate statistical methods to analyze data; develop and evaluate inferences and predictions that are based on data; and understand and apply basic concepts of probability.

The NCTM is not the only organization calling for the importance of statistics in the school mathematics curriculum. The National Assessment of Educational Progress Frameworks have been including statistics since 1973. Since then, the percentage of items classified as data analysis, statistics, and probability has almost doubled in grade 8 and more than tripled in grade 12 (Shaughnessy, 2007). Results from these assessments over time show that students' abilities to read tables and graphs, and their success at computing measures of center, are on the rise. However, their conceptual abilities to interpret and draw conclusion from graphs and to identify which measure of center is more appropriate are much weaker than their procedural skills (Tarr & Shaughnessy, 2007). More recently, in 2006, the College Board released its *College Board Standards for College Success: Mathematics and Statistics*, which includes topics and skills related to data analysis, statistics, and probability for middle school and high school grades.

Finally, the American Statistical Association (ASA) has also played an important role in the inclusion and emphasis of statistics in the school curriculum. In

1991, they published the *Guidelines for the Teaching of Statistics*, and in 2007, they published the *Guidelines for Assessment and Instruction in Statistics Education (GAISE) Report* (Franklin et al., 2007). The latest report builds on the recommendations given by the Join Curriculum Committee of the ASA and the MAA and suggests the following: (1) Emphasize statistics literacy and develop statistical thinking; (2) Use real data; (3) Stress conceptual understanding rather than mere knowledge of procedures; (4) Foster active learning; (5) Use technology to develop conceptual understanding and analyze data; and (6) Use assessments to improve and evaluate learning. The report also includes goals for students regarding what it means to be statistically educated and suggestions for implementing the goals.

The importance of statistics and probability in school mathematics is also reflected in the rapid growth, especially in the last 15 years, of the study of teaching and learning at all levels. Evidence of this is found in the extensive literature review by Shaughnessy (2007) in the *Second Handbook of Research in Mathematics Education* compared with the first handbook published in 1992. "[Educational] research in probability and statistics is no longer a fledgling discipline. . . . There has been an amazing boom in research, curriculum development, and assessment in statistics education" (p. 957). Now that we have statistics placed in the curriculum, have a growing knowledge of how students learn, and are developing instructional and assessment tools, the international community represented by the International Commission on Mathematical Instruction and the International Association for Statistical Education are taking the lead on the issue of teacher preparation by coordinating the 2008 Joint Study on "Statistics education in school mathematics: Challenges for teaching and teachers' education" in Monterrey, Mexico.

Besides the national standards mentioncd here, additional content standards/curriculum frameworks exist for almost every state in the country. The CSMC has conducted a survey of state-level curriculum standards and analyzed areas of mathematics but not including data analysis and statistics, such as numbers and operations, algebra, and reasoning (Reys & Lappan, 2007). These same state standards are examined and analyzed in the following sections to identify the statistical content and allow comparisons among states.

Methodology

Data Sources and Instrumentation

The data sources are content standards at the middle grades level from 49 states and the *Principles and Standards for School Mathematics* (NCTM, 2000). At the time of the study, the only state without any learning expectations or standards document was the state of Iowa. The documents were retrieved from the online database establish by the CSMC, which keeps the latest version of the state-level standards (http://mathcurriculumcenter.org/states.php).

Content standards vary in their structure and level of specificity from state to state. Some states present their standards in a general statement followed by a set of more specific standards. Others do not present any general statement and only list specific standards. In order to identify common content and the level of emphasis suggested by national and state standards in a systematic way, an instrument that identifies common language was needed.

Although there are several frameworks that organize content, including Bloom's taxonomy (Bloom, Englehart, Furst, Hill, & Krathwohl, 1956) and Third International Mathematics and Science Study (TIMSS) assessment framework (Valverde, Bianchi, Wolfe, Schmidt, & Houang, 2002), they are not suitable for this research. Bloom's taxonomy is not specific to mathematics, and the TIMSS assessment framework is not designed to compare or find commonality among different documents. The framework that better suits the purpose here is the *conteut matrix* developed by Porter, Kirst, Osthoff, Smithson, and Schneider (1993). This instrument was adapted to meet the needs of this study and to reflect the newly published GAISE Report.

The content matrix consists of two dimensions: topic coverage and level of cognitive demand. The *topic coverage* dimension consists of a comprehensive list of statistical topics at the middle school level organized by fundamental or big ideas. The *cognitive demand* dimension was defined as the cognitive activities that engagc students in the content topics; therefore, they are behaviorally defined. Table 1 gives the language associated with each category. A content topic is defined as the intersection of the two dimensions.

Five cognitive demands were used, and they are defined as in Porter (2002) but described here in the context of data analysis and statistics. For *memorize facts, defiuitious, formulas*, the content focuses on recalling traditional math skills and knowledge. An example of this would be recalling the formula for the

Table 1
Language Frequently Associated with Cognitive Demands

A	B	C	D	E
Memorize Facts, Definitions, Formulas	Perform Procedures/Solve Routine Problems	Communicate Understanding of Concepts	Solve Nonroutine Problems/Make Connections	Conjecture, Generalize, Prove
Recognize Identify Recall Recite Name Tell	Do computations Make observations Take measurements Compare Develop fluency	Communicate mathematical ideas Use representations to model mathematical ideas Explain findings and results from statistical analyses Explain reasoning Describe Select	Apply and adapt a variety of appropriate strategies to solve nonroutine problems Apply mathematics in context outside of mathematics Analyze data, recognize patterns Explore Judge	Complete proofs Make and investigate mathematical conjectures Infer from data and predict Determine the truth of a mathematical pattern or proposition

Note. From Porter (2002, p. 13).

mean. For *perform procedures/solve routine problems*, the content focuses on demonstrating basic skills, then selecting and applying various computational methods. In statistics, this is interpreted as creating graphs, computing measures of center or spread, and collecting data for analysis. For *communicate understanding of concepts*, the content focuses on students sharing their mathematical understanding in both oral and written form. In statistics, these activities include choosing the appropriate graph, measuring the center and the spread to answer questions about the data, as well as matching verbal descriptions of the data to distributions and their graphs. For *solve nonroutine problems/make connections* the content focuses on students applying mathematical knowledge to solve unfamiliar problems or seeing relationships between topics within mathematics and to other content areas. Examples of nonroutine problems include analyzing a complicated data set, recognizing patterns in data, and using statistics to explore real-world problems. Finally, for *conjecture, generalize, prove* students focus on making and justifying conjectures. In the context of statistics at the middle school level, this translates primarily to informal inference and prediction from data about real-world problems.

Coding. National and state standards were coded according to the topic and cognitive demand defined above. The coding process followed several principles to assure reliability of the instrument. The first principle was "stick to the language of the standard." Coders were instructed not to overgeneralize or to interpret intended topics that were not noted in the standard. Second, if the standard applied to more than one topic, all of those topics were coded. For example, consider the following standard: "select, create, and use appropriate graphical representation of data, including histograms, box plots, and scatterplots." This refers to two topics of the matrix, "numerical data representation" and "bivariate data representation," but not the topic "categorical data representation." Similarly for cognitive demand(s), if the standard was "describe the shape of the data using range, outliers, and measures of center, including the mean, median, and mode," the correct cognitive demand would be "communicating understanding." The raters did not assume that in order to "describe the shape of the data," the student would also be able to find or select measures of spread and center ("performing routine problems"), or to formulate conjectures or infer beyond the data. In the case where the standard did not specify whether the student should be able to solve routine or nonroutine problems, and it was not possible to determine whether the problem was routine or nonroutine from the context, then both cognitive demands were selected.

To further reassure the reliability of the coding process, one rater was trained to code the standards. The trained rater and the researcher coded the standards independently. The researcher adjudicated when there was disagreement. A total of 294 specific student standards were coded, and because each specific standard could receive one or more codes, there were a total of 806 codes recorded, with an average of 16.4 codes per state.

Results

Table 2 summarizes the distribution of statistical content for all 49 states and the NCTM standards by topics and levels of cognitive demand. The first result that stands out is the uneven distribution of the content. The most commonly observed statistical topics among all standards were categorical and numerical data representation, followed by measures of center. Categorical data representation often appeared in lower middle grades, while histograms and box-plots were introduced in upper middle grades. In terms of cognitive demand, the standards emphasized the proper selection of statistical data representations and measures and the explanation of results.

Figure 1 is a content map (which is similar to a topographical graph) of the results from Table 2. The grid overlaying the map identifies the seven topics or big ideas and the five levels of cognitive demand. The intersection of each topic and cognitive level represents a measurement node or code based on the documents analyzed. Even though the measurements are of discrete nature and topographical graphs may not be the most appropriate display, the content map creates a powerful description of the content emphasized (for more details on the construction see Blank, Porter, & Smithson, 2001.

It is now easy to see in Figure 1 that the content in statistics in middle grades is not suggested with the same emphasis. Two clusters are clearly identified with the greatest emphasis. One is the representation of data, particularly numerical representation at the level of understanding their proper use. Second are the measures of center at the same level of understanding of their proper use. That is, about 7% of the content suggested for middle grade teachers in these documents, as a whole, is dedicated to communicating understanding with graphical displays and measures of center.

Decreased emphasis is suggested for topics like measures of spread and bivariate data representation. In terms of cognitive demand, decreased emphasis is also suggested for construction of graphs/ computation and application to real problems and inferential statistics. The greatest emphasis of the standards and other documents is at the middle level

Table 2
Distribution of Topics and Levels of Cognitive Demand for Content Standards

Levels of Cognitive Demand	Big Ideas and Corresponding Topics							Totals
	Formulation of Questions, Designing Studies, Collect Data	Categorical Data Representation	Numerical Data Representation	Bivariate Data Representation	Shapes of Distributions	Measures of Center	Measures of Spread	
		Bar/Pie Graphs, Pictographs, Tables	Stem-and-Leaf Plots, Histograms, Box Plots	Scatter Plots, Line Graphs, Regression Line	Shapes of Data Distributions, Skewness, Gaps, Outliers, Clusters	Median, Mean, Mode	Range, IQR, Standard Deviation	
Memorize	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Perform procedures	35 (4.3%)	45 (5.6%)	46 (5.7%)	33 (4.1%)	15 (1.9%)	47 (5.8%)	41 (5.1%)	262
Communicate understanding	24 (3%)	55 (6.8%)	57 (7.1%)	43 (5.3%)	27 (3.3%)	51 (6.3%)	41 (5.1%)	298
Solve nonroutine problems	24 (3%)	21 (2.6%)	23 (2.9%)	22 (2.7%)	10 (1.2%)	27 (3.3%)	23 (2.9%)	150
Conjecture, generalize, prove	29 (3.6%)	15 (1.9%)	10 (1.2%)	15 (1.9%)	8 (1%)	9 (1.1%)	10 (1.2%)	96
Totals	112	136	136	113	60	134	115	806

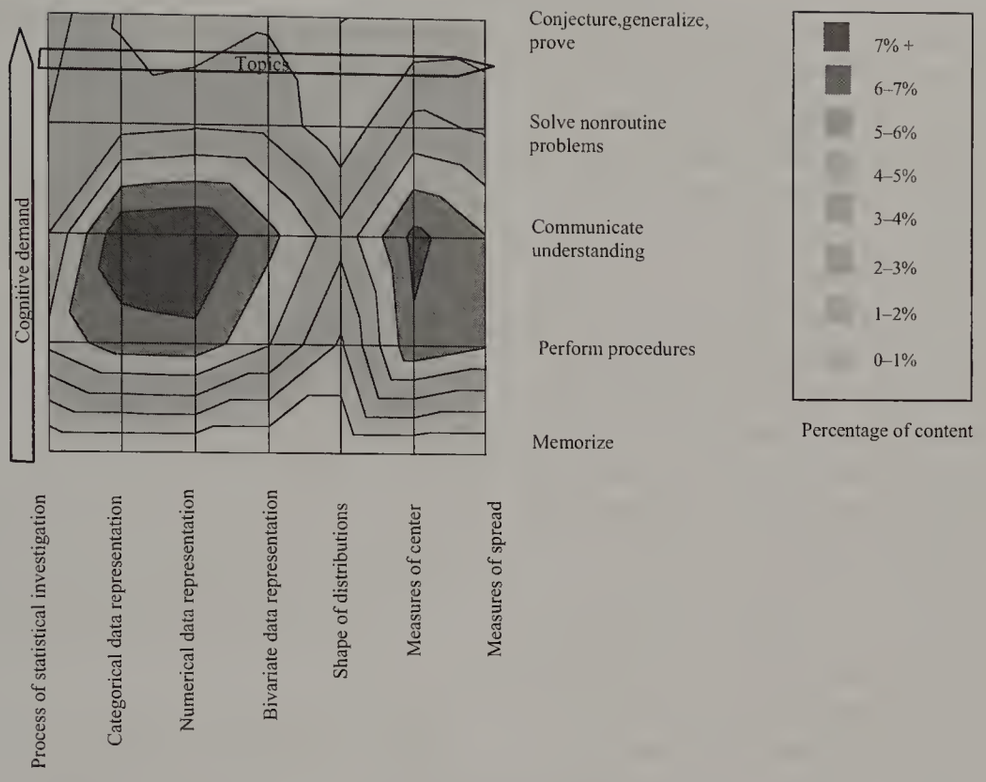

Figure 1. Content map for 49 states and *Principles and Standards for School Mathematics* (NCTM, 2000).

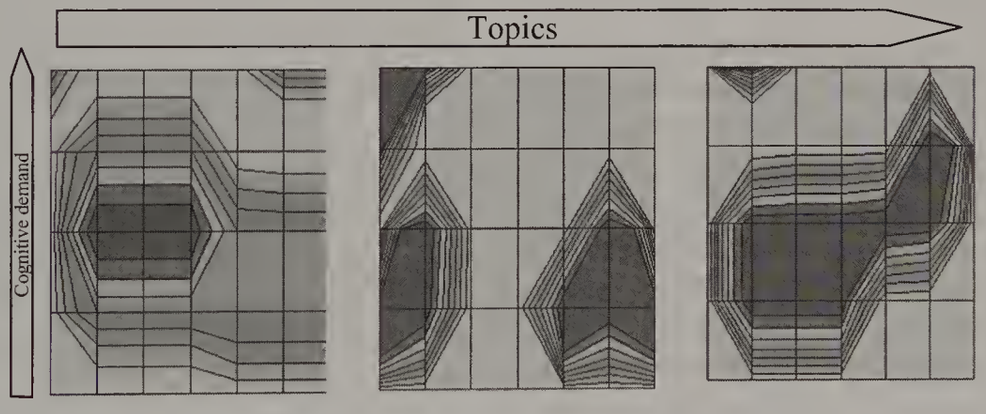

Figure 2. Content maps for three different states.

of cognitive demand. The map also indicates that the topic with the least emphasis is shapes of distribution at all levels of cognitive demand. As for the topic, process of statistical investigation, which refers to the understanding of that process by posing questions, collecting data, analyzing data, and making interpretations to answer questions, the results show moderate emphasis at the level of performing procedures. In this case, this refers to collecting data at the highest level—or making informal inferences or interpretations.

Figure 1 was constructed using the set of all documents as a whole. The patterns observed on individual state standards or other documents were found to be surprisingly different. The variation was considerable in both the topics they each chose to cover and the level of cognitive demand. Figure 2 shows three different states: The first shows more uniformity across topics and levels but with emphasis on data representation; the second shows well-defined clusters around categorical data representation and measures of center and spread at lower levels; and the third state shows

emphasis at all levels for different topics. Furthermore, when the common content among all documents was sought (i.e., the intersection of content) it was found that it was almost empty. The only topic in common was the proper use of measures of center.

Discussion

The statistical knowledge suggested for students to learn and teachers to teach at the middle school level in the United States is presented in documents like national and state standards or frameworks. Variation of content was observed between the documents, and variation on emphasis of the content was observed when the documents are taken as a whole. The variation of content among documents could be in part a result of the different views on how and when to teach statistics by the different states and to the different rates of reform. As we combine the standards and form a single summary, we add the dimension of how much emphasis is placed on a particular type of content at the national level.

For middle grades, the emphasis is no longer on categorical data representation such as pie and bar graphs (which, according to state and NCTM standards, is a content focus for elementary grades) but more on line plots, histograms, and stem-and-leaf plots. Moreover, the emphasis is less on the construction and more on the interpretation and proper use of the graphs. This is perhaps because of the introduction of new software and new technology that allows students and teachers to make graphical displays quickly and more accurately.

In terms of measures, the greatest emphasis is on the mean, median, and mode. However, the documents suggest going beyond the computation of these measures—recommended in lower grades—and emphasize their meaning and proper use according to the distribution of the data. The understanding of measures of spread such as the range and interquartile range had less emphasis but was still relevant.

The analysis also suggests that concepts of distribution and inferential statistics are left for upper grades; however, the few standards observed with this content suggest the introduction of these concepts in an informal way. These results are coherent with the most recent statistical research which suggests that students at the middle school level gain better understanding of graphs and measures of center and spread when confronted with tasks related to informal talk of variation, distributions, and inferential statistics (Bakker & Gravemeijer, 2004; Ben-Zvi, 2006; Reading & Shaughnessy, 2004).

Implications for Teacher Education

As the introduction of statistics and data analysis in K–12 curriculum is implemented and assessed across the United States, the need to prepare and assess future teachers in this area is essential. The decision on what teachers should know (the content) in order to teach at a specific grade level is a complex one. Too often this decision is based on the opinion of "an expert" or a group of experts within a college or university. The inclusion (or exclusion) of topics for future teachers needs to be aligned with the learning expectations for the students that the teachers are planning to teach and with the current teaching tools (textbooks, technology, etc.).

Another important aspect of this analysis that is helpful for teacher educators is the awareness that the content is not "flat"; that is, not everything is of equal importance. If educators are trying to train teachers to teach in any part of the country they cannot base the content on a single state standard, or even on the national standards. The single state standard is too limited in its view, and the national standards do not provide the needed emphasis on relevance because they are not likely to list a specific content more than once. By analyzing a set of these standards, a more complete view is exposed and the relevance of topics and cognitive levels are clearly identified. For instructional and developmental reasons this is very important when it comes to preparing future teachers.

Finally, the analysis presented here for middle school statistical content is a tool that can be used for developing courses and assessment instruments for future teachers. Content analysis serves as a validation tool as well as a guide to the weight (in terms of number of items) assessment instruments should have in terms of content covered. This methodology can be used with other areas of mathematics as well as other grade levels.

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PROBLEMS section

Ted Eisenberg, *Section Editor*

This section of the Journal offers readers an opportunity to exchange interesting mathematical problems and solutions. Please send them to Ted Eisenberg, Department of Mathematics, Ben-Gurion University, Beer-Sheva, Israel or fax to: 972-86-477-648. Questions concerning proposals and/or solutions can be sent e-mail to eisenbt@013.net. Solutions to previously stated problems can be seen at http://ssmj.tamu.edu.

Solutions to the problems stated in this issue should be posted before May 15, 2011

• **5152:** *Proposed by Kenneth Korbin, New York, NY*

Given prime numbers x and y with $x > y$. Find the dimensions of a primitive Pythagorean triangle that has hypotenuse equal to $x^4 + y^4 - x^2y^2$.

• **5153:** *Proposed by Kenneth Korbin, New York, NY*

A trapezoid with sides $(1, 1, 1, x)$ and a trapezoid with sides $(1, x, x, x)$ are both inscribed in the same circle. Find the diameter of the circle.

• **5154:** *Proposed by Andrei Răzvan Băleanu (student, George Cosbuc National College), Motru, Romania*

Let a, b, c be the sides, m_a, m_b, m_c the lengths of the medians, r the in-radius, and R the circum-radius of the triangle ABC. Prove that:

$$\frac{m_a^2}{1+\cos A}+\frac{m_b^2}{1+\cos B}+\frac{m_c^2}{1+\cos C}\geq 6Rr\left(\frac{a}{b+c}+\frac{b}{c+a}+\frac{c}{a+b}\right).$$

• **5155:** *Proposed by José Luis Díaz-Barrero, Barcelona, Spain*

Let a, b, c, d be the roots of the equation $x^4 + 6x^3 + 7x^2 + 6x + 1 = 0$. Find the value of

$$\frac{3-2a}{1+a}+\frac{3-2b}{1+b}+\frac{3-2c}{1+c}+\frac{3-2d}{1+d}.$$

• **5156:** *Proposed by Yakub N. Aliyev, Khyrdalan, Azerbaijan*

Given two concentric circles with center O and let A be a point different from O in the interior of the circles. A ray through A intersects the circles at the points B and C. The ray OA intersects the circles at the points B_1 and C_1, and the ray through A perpendicular to line OA intersects the circles at the points B_2 and C_2. Prove that

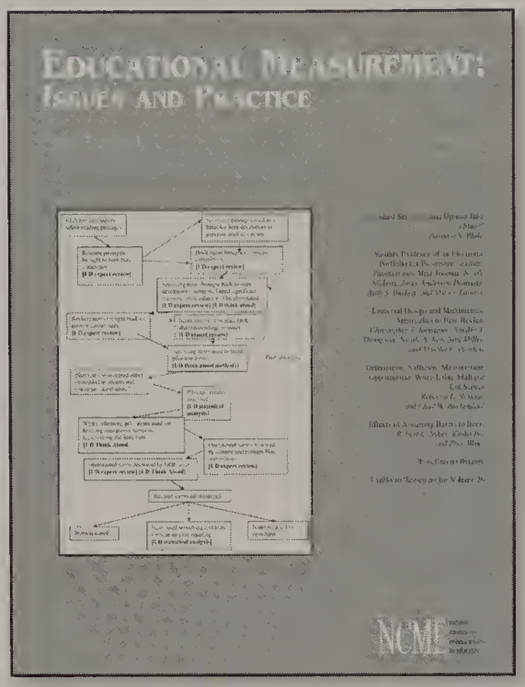
$$B_1C_1 \leq BC \leq B_2C_2.$$

• **5157:** *Proposed by Juan-Bosco Romero Márquez, Madrid, Spain*

Let $p \geq 2$, $\lambda \geq 1$ be real numbers and let $e_k(x)$ for $1 \leq k \leq n$ be the symmetric elementary functions in the variables $x = (x_1, \ldots, x_n)$ and $x^p = \left(x_1^p, \ldots x_n^p\right)$, with $n \geq 2$ and $x_i > 0$ for all $i = 1, 2, \ldots, n$.

Prove that

$$e_n^{(pk/n)}(x) \leq \frac{e_k\left(x^p\right) + \lambda\left(e_k^p(x) - e_k\left(x^p\right)\right)}{\binom{n}{k} + \lambda\left(\binom{n}{k}^p - \binom{n}{k}\right)} \leq \left(\frac{e_1(x)}{n}\right)^{pk}, \quad 1 \leq k \leq n.$$



EDUCATIONAL MEASUREMENT: ISSUES AND PRACTICE

Edited by
SUSAN M. BROOKHART

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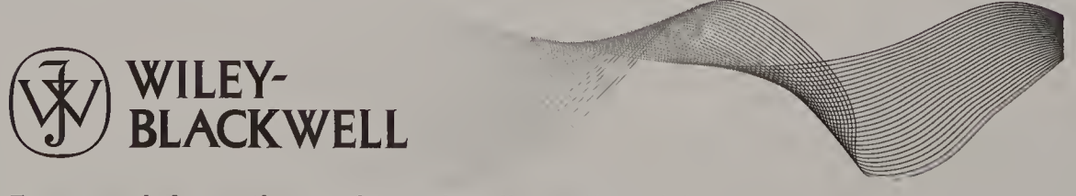

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Enough information to enable replication (quantitative)

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IN THIS issue

Exploring the Responses of Underrepresented Students in Science to an Elementary Classroom Outreach Program

Marie-Claire Shanahan, Erminia Pedretti, Isha DeCoito, Lindsay Baker

This paper describes a subset of results from a large-scale two-year independent evaluation study conducted with the *Scientists in School* (SiS) outreach program and two large school boards in Ontario, Canada. Specifically, it explores the responses of elementary students ($N = 811$) from typically underrepresented groups in science (English language learners (ELL), girls, and students at low-achieving schools) to the SiS outreach program. It explores responses related to enjoyment, interest, perceptions of role modeling, and future career choice in science. Compared to other students, findings suggest that girls and students from low-achieving schools found the program more enjoyable and reported that it provided positive science role models. Students at schools with high ELL populations also reported higher levels of enjoyment and reported that the program helped get them excited about science.

Student and Teacher Perspectives Across Mathematics and Science Classrooms: The Importance of Engaging Contexts

James J. Appleton, Frances Lawrenz

Substantial recent focus has been placed on the competitiveness of American students in increasingly global economies and entrepreneurial enterprises. As concerns center on students' educational preparedness and their efforts at continued learning, researchers acknowledge the importance of student engagement with school. In order to foster engaged learners, teachers must be able to determine and monitor their students' levels of engagement. The current study examined the alignment of perceptions of engagement by students, teachers, and outside observers across middle and high school mathematics and science classrooms. Results indicated significant teacher-student differences in perceptions of student cognitive engagement across mathematics and science classrooms with teachers consistently perceiving higher levels than students. Moreover, most effect sizes were moderate to large. A subsequent multi-level analysis indicated that while teacher perceptions of student cognitive engagement were somewhat predictive of student reported cognitive engagement, academic engagement ratings by outside observers were not.

Urban Third Grade Teachers' Practices and Perceptions in Science Instruction with English Language Learners

Scott Lewis, Jaime Maerten-Rivera, Karen Adamson, Okhee Lee

The study examined relationships among key domains of science instruction with English language learning (ELL) students based on teachers' perceptions of their classroom practices (i.e., what they think they do) and actual classroom practices (i.e., what they are observed doing). The four domains under investigation included: (1) teachers' knowledge of science content, (2) teaching practices to support scientific understanding, (3) teaching practices to support scientific inquiry, and (4) teaching practices to support English language development during science instruction. The study involved 38 third-grade teachers participating in the first-year implementation of a professional development intervention aimed at improving science and literacy achievement of ELL students in urban elementary schools. Based on teachers' self-reports, practices for understanding were related to practices for inquiry and practices for English language development. Based on classroom observations in the fall and spring, practices for understanding were related to practices for inquiry, practices for English language development, and teacher knowledge of science content. However, we found a weak to non-existent relationship between teachers' self-reports and observations of their practices.

Fundamental Fraction Knowledge of Preservice Elementary Teachers: A Cross-National Study in the United States and Taiwan

Fenqjen Luo, Jane-Jane Lo, Yuh-Chyn Leu

The purpose of this paper is to show the differences as well as the similarities of fundamental fraction knowledge owned by preservice elementary teachers

from the United States ($N = 89$) and Taiwan ($N = 85$). To this end, we examined and compared their performance on an instrument including 15 multiple-choice test items. The items were categorized into four different types of fundamental fraction constructs, including part-whole relationship, quotient, equivalence, and meanings of operations. Each item was embedded in the area, linear, or set model except for the items constructed out of the meaning of operations. Several items were featured with a pictorial illustration. Quantitative analysis showed that U.S. preservice teachers were significantly outperformed by their Taiwanese counterparts overall. The difference between the two groups was statistically significant on 12 of 15 items. Findings suggest that preservice elementary teachers from both countries need to be better prepared in their understanding of the meaning of fraction multiplication or division operations. Findings also suggest that U.S. preservice elementary teachers need to be more knowledgeable in dealing with fraction problems embedded in a linear model. Further research is suggested to study the issues raised from the findings.

Gender-Related Beliefs and Mathematics Performance of Preservice Primary Teachers

Adem Duru

The aim of this study was to examine whether there are gender differences in mathematics achievement and in beliefs about mathematics of preservice teachers over a period of four years. Data were collected from preservice teachers (156 males and 155 females) from Adıyaman University, Faculty of Education in Turkey. The Mathematics as a Gendered Domain instrument was used to investigate preservice teachers' beliefs about the gender differences in mathematics. The results indicated that gender had no effect on mathematics performances of the preservice primary teachers. Findings of this research show that most of the male and female preservice primary teachers do not gender-stereotype mathematics and believe that mathematics is gender neutral although there are gender differences on some types of items of instrument.

Exploring the Responses of Underrepresented Students in Science to an Elementary Classroom Outreach Program

Marie-Claire Shanahan
University of Alberta

Erminia Pedretti
University of Toronto

Isha DeCoito
York University

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This paper describes a subset of results from a large-scale two-year independent evaluation study conducted with the Scientists in School *(SiS) outreach program and two large school boards in Ontario, Canada. Specifically, it explores the responses of elementary students (*n = *811) from typically underrepresented groups in science (English language learners [ELL], girls, and students at low-achieving schools) to the SiS outreach program. It explores responses related to enjoyment, interest, perceptions of role modeling, and future career choice in science. Compared to other students, findings suggest that girls and students from low-achieving schools found the program more enjoyable and reported that it provided positive science role models. Students at schools with high ELL populations also reported higher levels of enjoyment and reported that the program helped get them excited about science.*

This paper describes a subset of results from a large-scale two-year independent evaluation study conducted with the *Scientists in School* (SiS) outreach program and two large school boards in Ontario, Canada. SiS is a non-profit organization consisting of over 320 scientists and technical experts who share their excitement and enthusiasm about science with elementary students and their teachers. They visit thousands of elementary classrooms and offer half-day workshops, in which students become "scientists in their school." The overall goals of the larger study were to: (1) conduct an external evaluation of the SiS outreach program; (2) explore the impact of SiS on teachers and students with respect to engagement and interest in the teaching and learning of science; and (3) explore the impact of SiS from the perspective of principals and parents. This paper addresses a part of the study that aims to explore students' responses to the program, particularly those who are typically underrepresented in science: English language learners (ELLs), girls, and students at low-achieving schools. Specifically, we explore their immediate responses to the program including enjoyment, interest, future career plans, and role modeling in science.

Context: Scientists in School

The Canadian Federation of University Women, Ajax-Pickering Branch, initiated SiS in 1989 in conjunction with the Durham District Board of Education. Since then, it has grown from a pilot program visiting 40 classrooms to a program that reaches almost 17,000 classrooms in 15 Ontario school boards each year. During the 2005–2006 school year, SiS reached over 450,000 young students, 16,500 teachers, and 43,000 parent volunteers through classroom workshops correlated with the Ontario Science and Technology Curriculum.

The primary goals of *Scientists in School* include presenting science and technology concepts in a hands-on manner to enhance students' attitudes toward science and to foster an appreciation and awareness of science and technology among *all* children regardless of gender and ability. Its vision includes inspiring elementary students and teachers to enjoy science and technology through fun and exciting

activities. Specifically, they seek to "inspire greater understanding and interest in all young minds" and to "expose students to the excitement and enjoyment of scientific discovery" (Scientists in School, 2004).

Science Outreach

SiS is an example of the type of outreach currently advocated by the scientific community. National organizations for science and science education, such as the Natural Sciences and Engineering Research Council of Canada (2004) and the National Science Foundation (2008) in the United States, have encouraged the involvement of scientists and engineers in K-12 classrooms to support teachers and promote scientific literacy for students. It is argued that these outreach programs provide an ideal opportunity to spark students' interest in science and open their eyes to the possibilities that exist in scientific careers (Atwater, Colson, & Simpson, 1999; Gibson & Chase, 2002; Knox, Moynihan, & Markowitz, 2003).

Wilson and Chizeck (2000) argue, however, that too many outreach initiatives are aimed at upper secondary students who have already made important decisions regarding their studies in science. They suggest that outreach programs aimed at high school students are generally not successful at encouraging individuals who would otherwise not have pursued studies in science. Koehler, Park, and Kaplan (1999) propose that outreach is most effective when aimed at elementary students: "It is well known that young children have a great deal of inherent scientific curiosity, but that a variety of factors tend to dampen this natural curiosity as early as the middle school years" (p. 1505). They posit that the key to bringing new students toward scientific careers and improving their scientific literacy is engaging them during their elementary years. As an elementary outreach program, SiS is, therefore, in a strong position to support elementary students to potentially develop positive attitudes toward science and to encourage students who might otherwise not consider a career or future studies in science.

In seeking to study elementary outreach programs, however, long-term impacts can be difficult to measure due to attrition, time lag, and the large number of other factors involved in students' course and career choices (Wilson & Chizeck, 2000). In addition, elementary programs often aim to broaden all students' interest in and appreciation of science, not just those who will pursue science in high school or as a career. Hence, in examining the SiS program, we chose to focus on questions pertaining to students' immediate responses to the program and questions inspired by the goals of the program (e.g., Did students find the program engaging, did it encourage their interest and their desire to pursue science?).

We have elsewhere described the overall positive response of all students to the program (Pedretti, Baker, De Coito, & Shanahan, 2006, 2007). A key aspect of SiS, however, is providing role models and encouragement for girls and other non-traditional science students. From this perspective, our focus narrowed: What are the responses to the SiS program of students who are typically underrepresented in science? (e.g., Did they find the program engaging, did it encourage their interest and their desire to pursue science, and how does this response compare to other students?).

Underrepresentation Among Science Students

Drawing on literature exploring various students' engagement, participation and interest in science, this paper focuses on three main aspects of underrepresentation among science students: language proficiency, gender, and school achievement.

ELLs

ELLs tend to develop deep frustrations in the science classroom. They drop out of high school science at a higher rate, receive lower scores on standardized tests and exhibit lower levels of conceptual understanding (Lee, 2005; Ruiz-de-Velasco & Fix, 2000; Torres & Zeidler, 2002). A report from the U.S. National Center for Education Statistics (2000) indicates that Latino students in particular score, on average, 20 points below their classmates on achievement tests in science, mathematics, and reading. On the TIMSS 2003, at both the eighth- and fourth-grade levels, students who spoke the dominant instruction language at home had higher average achievement in science than those who did not or who did so rarely (Martin, Mullis, Gonzalez, & Chrostowski, 2004).

Addressing the needs of ELLs in North America is particularly important, as both Canada and the United States continue to become more linguistically diverse. For example, in the Toronto District School Board (TDSB), Canada's largest school board serving over 280,000 students (and one of the partner school boards of SiS), 41% of elementary school students have a language other than English as their primary language (Toronto District School Board, 2010). From 1990 to 2000, the ELL population in American schools grew

by 105%, while the total general enrollment has grown by only 12% (Kindler, 2002). As of the 2002–2003 school year, more than five million school age children (approximately 10% of the total school age population) were classified as ELL (Genesee, Lindholm-Leary, Saunders, & Christian, 2005).

Academic subjects, such as science, are especially challenging for students who are also learning the language of instruction because these subjects require not only proficiency in English communication, but also the use of highly specialized vocabulary and syntax (Genesee et al., 2005; Hart & Lee, 2003). Learning the language of science is similar to learning a new language. Many of the difficult conceptual words such as power, energy, and force, have one meaning in everyday vernacular, and quite another meaning in the context of science learning (Fang, 2006; Wellington & Osborne, 2001). Familiar words suddenly have unfamiliar meanings in new contexts for ELLs (and all students for that matter). Furthermore, the use of specialized language for hypothesizing, classifying, interpreting, predicting, and inferring is considered essential for inquiry science (National Research Council, 2000).

The difficulties encountered by these students are exacerbated by the fact that even in transitional or maintenance bilingual programs—designed to support content learning in students' mother tongue—science is most often taught in English (Amaral, Garrison, & Klentschy, 2002; Hart, & Lee, 2003; Lee, 2005). Instructional time for science can also be limited in schools with large populations of ELL students due to the perceived urgency of developing core literacy and numeracy skills (Lee, Maerten-Rivera, Penfield, LeRoy, & Secada, 2008). As Lee et al. argue:

> Ideally, content area instruction should provide a meaningful learning environment for English and literacy development; while improving English skills should provide the medium for understanding academic content. In reality, however, English language learners (ELL) students frequently confront the demands of academic learning through a yet-unmastered language *without* the instructional support they need. (p. 32)

For these reasons, outreach programs especially those offering hands-on engagement may play an important role in supporting ELL students. Hands-on programs offer the potential of low-stress engagement with science and scientific language, while participating in activities that reduce the dependence on language proficiency (Hart & Lee, 2003; Lee, 2005). We are interested in whether the students' responses to SiS support this relationship.

Girls in Science

A second central group of underrepresented students in science are girls. The representation of women in scientific fields of study has inspired considerable research and debate among educators and sociologists of science (for an historical overview, see Eisenhart & Finkel, 2001). At present, the main message is that girls and women are still underrepresented in many science-related fields despite the best efforts of teachers and researchers. Progress has been made and the proportion of female representation in undergraduate science programs has increased since the 1960s, when efforts to recruit women first began in earnest (Brainard & Carlin, 2001). However, this advancement has slowed and, in some disciplines, stopped completely (Ivie & Ray, 2005). Representation is particularly low in physical science and engineering programs where it remains around 20% (National Science Board, 2006).

Despite strong abilities and preparation, qualified girls and women drop out of science throughout the course of the high school, college, and graduate study pipeline, at higher rates and earlier than do men (Burke, 2007; Jones, Howe, & Rua, 2000). The fact that these trends occur even among the academically talented or when performance differences have been controlled for suggests that the problem is not ability, under preparedness, or merely unequal treatment (Cavallo, Potter, & Rozman, 2004; Hazari, Tai, & Sadler, 2007; Lee, 2002), but the very way that educators cultivate student interest in and connection to the field of science (Brickhouse & Potter, 2001; Brotman & Moore, 2008; Lee). Programs that address girls' interest, motivation, and attitudes toward science are key to fixing this leaky pipeline (Jacobs & Simpkins, 2005).

Students at Low-Achieving Schools

In addition to girls and ELL students, another group of students that has recently begun to come to the attention of science educators includes those attending low-achieving schools: schools with below average or below standard scores on provincial, state, or national achievement tests. While this trend has not yet been documented in Canada to the same degree, in the United States, one of the implications of policies such

as *No Child Left Behind* is that schools not meeting expectations are under extreme pressure to improve student achievement in the areas of literacy and numeracy. This is especially true at the elementary level where the outcome of low scores is often severe reductions in science instructional time due to the urgency of literacy and numeracy programs (Lee et al., 2008). Jones, Jones, Hardin, and Chapman (1999) documented the beginnings of an alarming trend where, in under-achieving schools, back to basics curricula are often implemented such that "science, social studies and the arts are subjects that are pushed aside and taught only if there is time left in the schedule" (p. 199). Principals and superintendents are directing teachers to engage in math and literacy instruction to prepare students for further testing even if it means less time for science and social studies. They highlight the experience of one distressed teacher who reports that "Teachers went from being involved in hands-on instruction in science several days a week, to using worksheets and relying on the textbook for core reading, to teaching no science at all" (Jones et al., p. 200).

The difficulties faced by students at low-achieving schools are further emphasized by findings that not only is instructional time often lower, but these students also develop more negative attitudes toward science. Using TIMSS data, Martin, Mullis, Gregory, Hoyle and Shen (2000) found that a significantly smaller percentage of students from low-achieving school reported positive attitudes towards science. The students reported liking science less and finding science less enjoyable than students at higher achieving schools. These factors suggest that students at low-achieving schools are a third important population to be investigated in relation to their experiences with outreach programs.

Based on the previously mentioned framework, the analysis that follows will address the primary question: How do students from three traditionally underrepresented groups in science respond to the SiS program in comparison to other students? The literature suggests these students may have, for example, more negative attitudes toward science or lower interest in science. It is important to ask if this is also true in their response to an outreach program that specifically aims to engage *all* students in science. This broader question will be addressed through the examination of three focus questions. For students in Grades 1–4 and 5–8:

1. Do students at schools with high ELL populations respond differently to questions related to enjoyment, engagement and role modeling associated with the SiS program than those at schools with low ELL populations?
2. Do girls respond differently to these questions than boys?
3. Do students at low-achieving schools respond differently to these questions than students at high achieving schools?

In setting our research goal, it is important to recognize that this is not an intervention or explanatory study assessing before and after measures for the students involved. It is specifically, and by design, a descriptive observational impact study hoping to gain insight into a particular program and the responses of particular target participant groups.

Methods

This paper, addressing the responses of ELL students, girls, and students at low-achieving schools, represents one part of a large-scale two-year independent evaluation of the SiS program. The larger study was a mixed-methods study involving recent SiS participants, past participants, participants' parents, and cooperating teachers and their principals (Pedretti et al., 2006). In this paper, the analysis will focus on a large set of quantitative responses from recent SiS participants. We have chosen to focus solely on the quantitative data because the interviews were conducted within the framework of a single-school case study, offering little insight into differences among students attending low-achieving or high ELL population schools. In addition, achievement and ELL status data could not be collected from the individual students due to ethical considerations. Therefore, the questions addressed by this study could only be explored through the available quantitative data. Student results from the qualitative responses (in the form of interviews, field notes, and classroom observations) can be found in three case studies described elsewhere (Pedretti et al.).

Participants

Participants ($N = 811$) were recruited from regular classrooms in two large school boards in southern Ontario. Participating classes had all recently participated in an SiS workshop and the students completed a short questionnaire following the workshop. Approximately half of the participants were in Grades 1 to 4 ($n = 403$) and half were in Grades 5 to 8 ($n =$

408). The sample was also roughly balanced between male (n = 392) and female (n = 419) students and represented a broad cross-section of schools in the area. The participating classes and schools were community catchment-based schools, generally without magnet programs for gifted students, ELL students, or other specialty programs. Therefore, the classifications of the schools with respect to English language learning represent, in most cases, descriptions of the students in the surrounding communities and catchment areas.

Data Collection

Classroom packages were sent to 76 classrooms in each board (152 classes in total) that were receiving SiS workshops during the research period. Specific classrooms were chosen based on the timing of their workshops (within the data collection window) and to maintain representative distribution of urban and rural schools across the socio-economic spectrum of the area. Each classroom package included student questionnaires inviting students to respond based on their most recent SiS workshop and any workshops that they had experienced in the past. The questions were designed by the researchers to address students' responses to the SiS program and the ability of the program to engage students and inspire interest. The questionnaires used by students in Grades 1 to 4 consisted of five items, each measured using a three-point Likert-type response format (3 = ☺ yes, 2 = 😐 a little, 1 = ☹ no):

1. SiS makes science fun.
2. SiS gets me excited about science.
3. SiS makes me want to learn more about science.
4. I enjoy doing the activities with SiS.
5. I would like SiS to visit my class more often.

The questionnaires for students in Grades 5 to 8 consisted of nine items measured with a five-point Likert-type response format (5 = strongly agree, 4 = agree, 3 = undecided, 2 = disagree, 1 = strongly disagree):

1. SiS presentations made science learning enjoyable.
2. SiS provided hands-on activities that I didn't experience normally in my elementary classroom.
3. SiS presentations made me more confident in my ability to do science.
4. SiS presentations sparked my interest in science and/or technology.
5. SiS presentations helped me better understand the science we did in class.
6. SiS presentations helped me develop more positive attitudes toward science.
7. SiS presentations provided positive role models for me.
8. The SiS program encouraged me to consider a career in science and/or technology.
9. SiS is a program that all students should experience in their elementary classes.

Analysis

To begin the analysis, all survey data were input into SPSS. Cases with missing data were deleted list-wise. For each item, descriptive statistics were explored. Group comparisons were conducted using Mann-Whitney U. The Mann-Whitney test is analogous to an independent sample t-test, but it is a non-parametric test appropriate for ordinal data. Group comparisons were done based on three variables: gender, school ELL population, and school achievement on provincial standardized tests. Note that a group variable had to be used for the ELL grouping because language data for individual students could not be collected due to school board policies on personal information. For the ELL variable, students were assigned to one of two groups: those whose schools had an ELL population percentage above the group mean of 20% and those with an ELL population percentage at or below the group mean. For school achievement, students were grouped by the percentage of students who met or exceeded the provincial standard on the Education Quality and Accountability Office (EQAO) provincial math assessment (Grade 3 for the comparisons involving students in Grades 1–4 and Grade 6 for those involving Grades 5–8). Note that school achievement and school ELL population were not significantly correlated and, therefore, these groups were not considered to represent the same underlying differences in the schools.

To supplement the findings of the group comparison significance tests, the common language effect size statistic (McGraw & Wong, 1992; Newcombe, 2006; Vargha & Delaney, 2000) was used to establish the practical significance of the group comparisons. The value of the statistic, measured from 0 to 1, represents how often a score sampled randomly from one group of participants would be expected to be greater than a score sampled randomly from the other. In this study, we have used the point estimation of the effect statistic (A) suggested by Vargha and Delaney that adapts the common language effect statistic to ordinal data situations to account for the possibility that the scores form the two groups may be equal.

In conducting the Mann-Whitney *U* tests, issues of multiple comparisons were also taken into consideration. We remained cautious about the possibility of increasing Type 1 error (finding a significant difference where one does not truly exist) by conducting multiple tests on the same group of participants. It was noted, however, that due to the use of three different groupings (gender, school ELL population, and school achievement), the maximum number of comparisons within the same population was five for students in Grades 1–4 and nine for students in Grades 5–8. This is relatively small in comparison to the general literature on multiple comparisons often arising from large epidemiological studies (e.g., Witte, Elston, & Cardon, 2000) and, therefore, the increase in Type I error is also relatively small. Taking into consideration that the typical procedure for dealing with multiple comparisons, the Bonferroni adjustment, subsequently increases the possibility of Type II error (failing to find a significant difference where one truly exists) and the relatively small change in Type I error, we decided against conducting this adjustment. The results should be interpreted, however, with the caution that finding a significant difference was slightly increased by the multiple comparison procedure.

Results

Grades 1 to 4

To begin the analysis, the median values of the five questionnaire items were explored. All items had medians corresponding to the highest value in the response format, and all included answers representing the full range of values from "Yes" (3) to "No" (1). Frequency plots demonstrated that the majority of students answered "Yes" to all of the questions, indicating a very positive overall response to the program. Students' enjoyment of the program was particularly high.

To explore differences in student responses, the Mann-Whitney *U* test was used (see Table 1 for all group comparison results for Grades 1–4). The test was first used to explore differences by ELL population: those whose schools had an ELL population percentage above the group mean of 20% and those with an ELL population percentage at or below the group mean ($n_{above} = 154$, $n_{below} = 249$). With this grouping, three significant differences were found. Students at schools above the group ELL average gave significantly higher ratings to three of the items. For Item 1, they rated their perception that SiS makes science fun higher than their counterparts at schools below the group ELL average ($z = -2.75$, $p = .01$, $A = .56$). For Item 2, they rated their perception that SiS gets them excited about science higher than their counterparts at schools below the group ELL average ($z = -2.12$, $p = .03$, $A = .56$). Finally, for Item 4, they rated their enjoyment of the activities and experiments higher than their counterparts at schools below the group ELL average ($z = -2.54$, $p = .01$ $A = .56$). See Figures 2–4 for the frequency differences in students' responses grouped by ELL school population.

Next, the responses were explored by gender ($n_{boys} = 216$, $n_{girls} = 187$) where one item showing a significant difference. For Item 4 ("I enjoy doing the activities with SiS"), female students gave significantly higher ratings to their enjoyment of the SiS activities ($z = -1.98$, $p = .04$, $A = 0.54$).

Finally, students were also grouped by school characteristics including percentage of students who met

Table 1

Summary of Mann-Whitney U Test Statistics for Items 1–5 with Students Grouped by Gender, School Achievement, and School ELL Percentage (Grades 1–4)

Item	Gender		Achievement		ELL	
	z	*p*	*z*	*p*	*z*	*p*
SiS makes science fun!	−1.79	.07	−0.88	.38	−2.75	.01
SiS gets me excited about science.	−1.37	.17	−1.63	.10	−2.12	.03
SiS makes me want to learn more about science.	−1.22	.22	−1.15	.25	−1.79	.07
I enjoy doing the activities with SiS.	−1.98	.04	−0.88	.38	−2.54	.01
I would like SiS to visit my class more often.	−0.99	.32	−0.68	.49	−1.45	.15

Table 2

Summary of Mann-Whitney U Test Statistics for Items 1–9 with Students Grouped by Gender, School Achievement, and School ELL Percentage (Grades 5–8)

Item	Gender		Achievement		ELL	
	z	*p*	*z*	*p*	*z*	*p*
SiS presentations made science learning enjoyable.	−0.49	.62	−2.02	.04	−0.94	.35
SiS provided hands-on activities that I didn't experience normally in my elementary classroom.	−0.09	.93	−1.36	.17	−1.26	.21
SiS presentations made me more confident in my ability to do science.	−1.17	.24	−1.10	.27	−1.82	.07
SiS presentations sparked my interest in science and/or technology.	−0.29	.77	−1.27	.21	−1.89	.06
SiS presentations helped me better understand the science we did in class.	−1.91	.06	−1.60	.11	−0.07	.94
SiS presentations helped me develop more positive attitudes toward science.	−1.35	.18	−0.30	.76	−1.16	.11
SiS presentations provided positive role models for me.	−2.21	.03	−2.89	<.01	−1.20	.23
The SiS program encouraged me to consider a career in science and/or technology.	−1.21	.23	−0.33	.74	−2.43	.02
SiS is a program that all students should experience in their elementary classes.	−1.54	.13	−0.75	.45	−1.31	.19

or exceeded the provincial standard on the Grade 3 EQAO math assessment (above and below the provincial average) (n_{above} = 277, n_{below} = 126). Using the Mann-Whitney *U* test, no significant differences were found.

Grades 5 to 8

To begin the analysis, the medians of the nine questionnaire items were explored. All items had medians of either 3 ("Undecided") or 4 ("Agree"), and all included answers representing the full range of values from "Strongly Agree" (5) to "Strongly Disagree" (1). Frequencies demonstrated that the majority of students answered "Agree" or "Strongly Agree" to six out of nine questions. Responses were especially high for Item 2 ("SiS provided hands-on activities that I didn't experience normally in my elementary classroom") and relatively low for Item 8 ("The SiS program encouraged me to consider a career in science and/or technology").

After exploring the whole group results, a Mann-Whitney *U* test was conducted to explore differences in students' responses by ELL population (n_{above} = 110, n_{below} = 298) (See Table 2 for all Mann-Whitney results for Grades 5–8). With this grouping, one significant difference was found. For Item 8 ("The SiS program encouraged me to consider a career in science and/or technology"), they rated their agreement higher than their counterparts at schools below the group ELL average, z = −2.43, p = .02, A = .59. Figure 1 summarizes the students' responses to Item 8 by ELL population.

Next, the students' responses were explored by gender (n_{boys} = 176, n_{girls} = 232). One item showed a significant difference by gender: On Item 7 ("SiS presentations provide positive role models for me."), the female students gave higher ratings to their perception that SiS provided role models for them (z = −2.21, p = .03, A = .57), indicating a positive response to SiS's efforts to bring a diverse group of scientists (including women) into classrooms. Figure 2 summarizes the students' responses to Item 7 by gender. The figure illustrates that girls assigned positive or neutral scores for role modeling substantially more often than did boys. It is interesting to note, however, that the percentage responded "Strongly Agree" is almost identical for the boys and the girls.

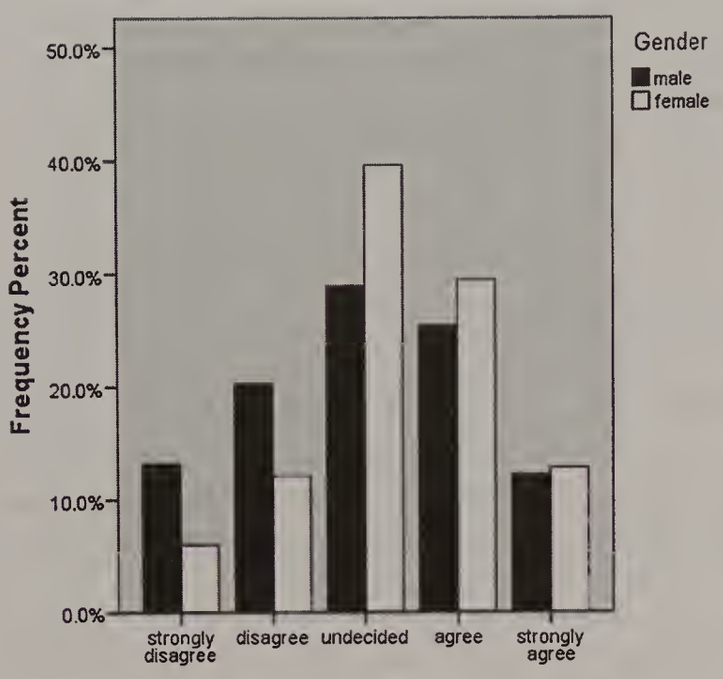

Figure 1. Item 7 ("SiS presentations provided positive role models for me") frequency percentages for Grade 5–8 students grouped by gender.

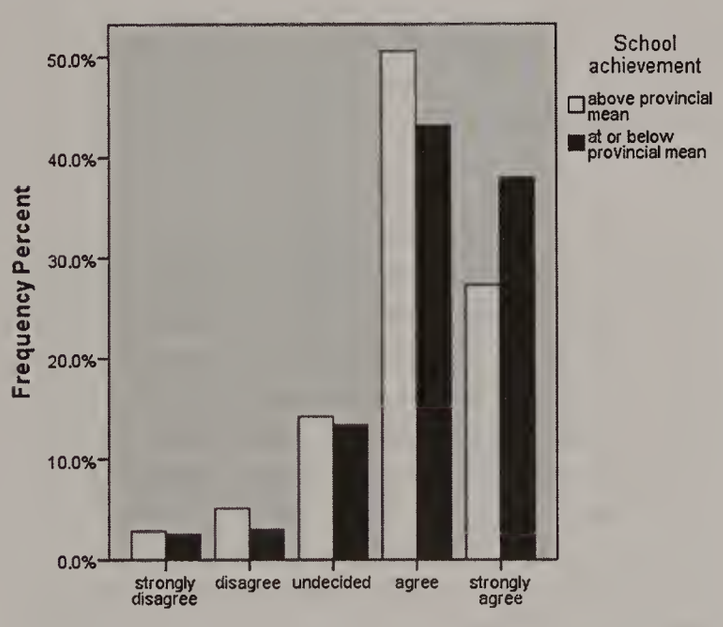

Figure 2. Item 1 ("SiS presentations made science learning enjoyable") frequency percentages for Grade 5–8 students grouped by school achievement.

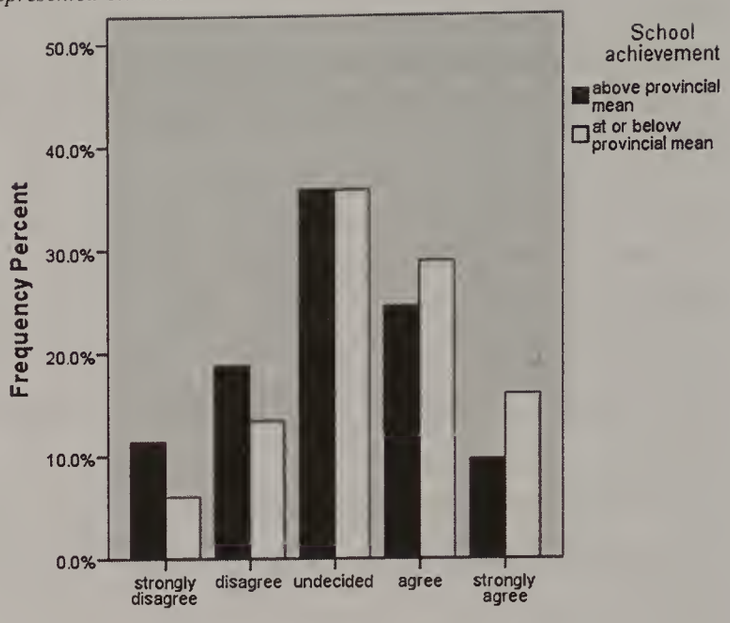

Figure 3. Item 7 ("SiS presentations provided positive role models for me") frequency percentages for Grade 5–8 students grouped by school achievement.

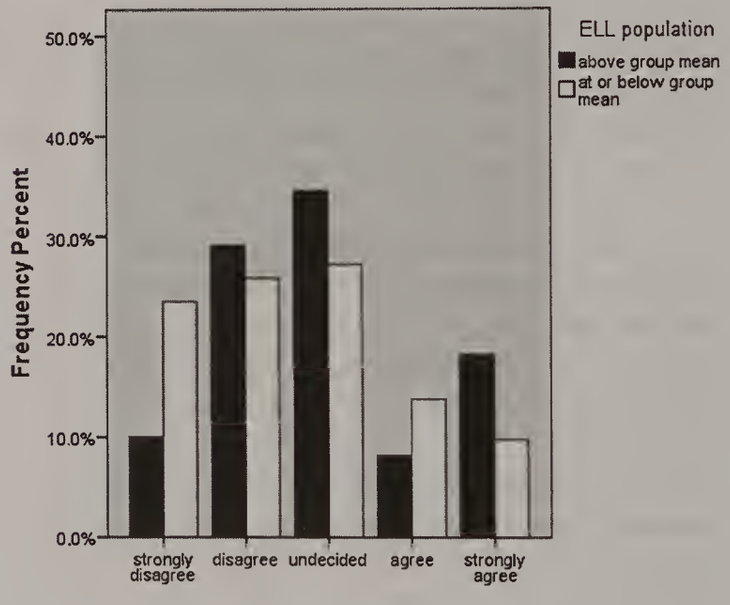

Figure 4. Item 8 ("SiS made me think about a career in science") frequency percentages for Grade 5–8 students grouped by school ELL population.

A similar test was conducted to explore differences related to school achievement based on the EQAO math results (above and below the provincial average) (n_{above} = 176, n_{below} = 232). Two items showed significant differences for these students. Students at lower-achieving schools gave Item 1 ("SiS presentations made science learning enjoyable") and Item 7 ("SiS presentations provided positive role models for me") higher ratings than their counterparts at higher achieving schools, $z = -2.02$, $p = .04$, $A = .56$ and $z = -2.89$, $p < .01$, $A = .59$ respectively. Figures 3 and 4 summarize the students' responses to Items 1 and 7 by school achievement. Figure 3 illustrates that the frequency of negative responses to the enjoyment item were similar for both groups, but that those at

low-achieving schools were more likely to respond in the extreme positive than were the others. Figure 4 illustrates that in response to the role models provided by SiS, students at low-achieving schools were more likely to respond positively (in the moderate and extreme positive) than were the others. This suggests a strong and consistent impact of the SiS role models on students at low achieving schools.

Discussion and Conclusions

The ultimate goal of the larger study was to determine if SiS is meeting its stated goal of seeking to inspire appreciation, interest, and awareness in science among *all* students regardless of gender, language, and ability. In response to this goal, the analysis presented in this paper was guided by the question: How do students from three traditionally underrepresented groups in science (ELL students, girls, and students at low-achieving schools) respond to the SiS program in comparison to other students? Do students at low-achieving schools, for example, in keeping with the TIMSS findings, express lesser attitudes towards science through their responses to the SiS program or do they respond equally positively?

The group comparisons illustrate not a single example of target students responding less positively to the program than other students. We see from these results a snapshot of an outreach program that is reaching and affecting its intended audiences: all students regardless of gender, language and ability. Encouragingly, we also see a few examples of girls and students at high ELL and low-achieving schools responding even more positively than other students. This is particularly evident for the students at high ELL schools who responded strongly regarding their enjoyment and excitement toward the program (Grades 1–4) and the career encouragement that it gave them (Grades 5–8). These responses to a hands-on outreach program such as SiS support arguments from Lee et al. (2008) and Hart and Lee (2003) regarding the potential value of hands-on experiences for ELL students in particular. For example, Lee et al. (2008) argue that "hands-on activities are less dependent on formal mastery of the language of instruction, thus reducing the linguistic burden on ELL students" (p. 33). Hart and Lee also argue that collaborative work in small groups provides authentic opportunities for students to develop more contextualized language skills, and that the nature of hands-on exploration provides accessible in-roads to scientific knowledge and scientific language when compared to decontextualized textbook- or worksheet-based transmission models.

Although our study can in no way measure or capture students' achievement after having participated in SiS workshops or the long-term effects of their participation, we can speculate that enhanced engagement and enjoyment may lead students (particularly underrepresented students) to remain in science longer during their formal education years. In relation to the larger body of literature on outreach programs, the overall positive results are similar to those presented by other researchers (Atwater et al., 1999; Bottomley & Parry, 2002; Knox et al., 2003) who report improved confidence in scientific skills and reported positive feelings of program enjoyment and program impact. It is likely that the particular types of hands-on activities in which students are engaged, exposure to materials and resources that students may not ordinarily come across in their schools or at home, and the positive role modeling are key components of the positive experiences reported by our participants.

In reporting these positive impacts, however, we recognize that it is difficult to draw far-reaching conclusions from a program that offers only short-term experiences for students and teachers (although the program does often revisit schools and classrooms over multiple years). Amaral, Garrison, and Klentschy (2002), for example, noted that in an inquiry-oriented program, the short-term results were positive, but it was long-term exposure that had lasting consequences, and they found a direct relationship between the length of engagement and the understanding and achievement gains of ELL students. In reporting our results, we are cognizant of the potentially short-term nature of the program, but encouraged by the positive results across a large sample of students and the ways in which they support the findings and arguments in the literature.

From the data collected in this study, it is also impossible to attribute students' positive responses to SiS to one specific aspect of the program. However, drawing on our large-scale study results and on research literature, we can begin to hypothesize regarding why students (particularly underrepresented students) responded so positively to the program, and what the implications are for teaching and learning science. The results of the study (that underrepresented students respond as positively or in

some case more positively than others to SiS) suggest that outreach programs can provide a kind of cultural capital (Apple, 2004) for disenfranchised and/or underachieving schools. Apple argues that schools re-create the social and economic hierarchies of the larger society through processes of selection and instruction. According to Bourdieu (1990) schools assume the "cultural capital" of the middle class, and use it as if all children have had equal access to it. If we consider school science that occurs in underachieving schools, "cultural capital" is potentially lost on two fronts: these very schools are often the ones that are poorly equipped and teaching less science; and it cannot be assumed that students have equal access to cultural capital in and beyond school. In a recent study, Lee et al. (2008) report that underachieving schools (particularly at the elementary level) often experience reduction in science instruction due to an increased emphasis on literacy and numeracy. When fewer resources are put toward science materials and equipment, there is often a return to textbook/worksheet teaching. Our study suggests that outreach programs have the capacity to fill the gaps and provide "cultural capital" for these schools and their students.

Given these potential benefits, one is left, however, with the question of access when there are costs associated with outreach programs. Often, low-achieving schools are located in the inner city, or in neighborhoods with low socioeconomic status, making cost a potentially inhibiting factor. Science supplies and specialized science programs are often not available in these schools (Hewson, Kahle, Scantlebury, & Davis, 2001; Spillane, Diamond, Walker, Halverson, & Jita, 2001) despite evidence, such as ours, that it may be these students with the most to gain from them. In interpreting the positive results of this study and supporting efforts to engage students in hands-on science, the issue of equitable access must not be neglected. It is hoped that our findings can support outreach organizations in expanding efforts to ensure that they are reaching and engaging underrepresented students who may have much to gain from them.

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Student and Teacher Perspectives Across Mathematics and Science Classrooms: The Importance of Engaging Contexts

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Substantial recent focus has been placed upon the competitiveness of American students in increasingly global economies and entrepreneurial enterprises. As concerns center on students' educational preparedness and their efforts at continued learning, researchers acknowledge the importance of student engagement with school. In order to foster engaged learners, teachers must be able to determine and monitor their students' levels of engagement. The current study examined the alignment of perceptions of engagement by students, teachers, and outside observers across middle and high school mathematics and science classrooms. Results indicated significant teacher-student differences in perceptions of student cognitive engagement across mathematics and science classrooms with teachers consistently perceiving higher levels than students. Moreover, most effect sizes were moderate to large. A subsequent multi-level analysis indicated that while teacher perceptions of student cognitive engagement were somewhat predictive of student reported cognitive engagement, academic engagement ratings by outside observers were not.

Much focus has been placed upon the changing role of the United States in an increasingly interdependent world. A large portion of that focus has centered upon the mathematics and science literacy of U.S. students relative to both global counterparts and less industrialized world neighbors (National Academy of Sciences, National Academy of Engineering, and Institute of Medicine [NASNAEIM], 2007). Rapid technological advancements have rendered distances between countries much less significant and provided many formerly excluded countries with ready access to international markets (Friedman, 2005). In a time when greater access to many enterprises is readily at hand, the mathematical and scientific literacy of students of several countries continues to surpass and sometimes outpace that of the United States (Gonzales et al., 2004, 2008; Organisation for Economic Co-Operation and Development [OECD], 2007).

Amid higher expectations and increased concerns of achievement gaps, educators and researchers have searched for improved means for motivating students in educational tasks en route to improved academic performance. One construct receiving considerable attention for its potential to improve academic performance is student engagement with school (e.g., Fredricks, Blumenfeld, & Paris, 2004; National Research Council and Institute of Medicine [NRCIM], 2004). Researchers have noted that specific, alterable indicators of student engagement are dynamic, vary within more static demographic categories of risk for underachievement, and predict important academic and behavioral outcomes (Christenson & Anderson, 2002; Finn & Rock, 1997; Miller, Greene, Montalvo, Ravindran, & Nichols, 1996; Ryan, Stiller, & Lynch, 1994).

Despite considerable optimism for its potential, efforts to improve student levels of engagement with school may encounter several contextual challenges during implementation (Blumenfeld, Kempler, & Krajcik, 2006). As noted by Blumenfeld and colleagues, engagement-focused environments require not only higher student levels of self-regulation and strategy use, but also more investment and effort. Moreover, student perceptions of contexts are critical in facilitating engagement (Connell & Wellborn, 1991) even as teachers serve an instrumental role in shaping those contexts. Given the interdependent nature of student perception and teacher influence, the alignment of student and teacher perceptions of engagement within a given learning environment is a crucial area of study.

Toward that end, the purposes of this paper are to discuss current conceptualizations of the student engagement construct and to examine data on

perceptions of student engagement in science and mathematics classrooms from three perspectives: student, teacher, and outside observer. Two research questions will be addressed: (a) given the instrumental role of the teacher in constructing the classroom context, how closely do teacher perceptions of student levels of cognitive engagement align with student responses, and do differences in alignment exist between science and math classrooms? and (b) are student levels of cognitive engagement better predicted by third-party observations of academic engagement or teacher perceptions of cognitive engagement?

Mathematics and Science Literacy

While primary and secondary level national assessments in mathematics and science indicated improved performance for fourth and some eighth grade U.S. students (Grigg, Lauko, & Brockway, 2006; Lee, Grigg, & Dion, 2007), international findings suggested a different result. National data suggested improved overall mathematics performance for both fourth and eighth grade American students from 1990 to 2005 and again from 2005 to 2007 (Lee et al.). Likewise, overall fourth grade science performance indicated that American students improved both between 1996 and 2000 as well as 2000 and 2005. Of concern at the national level, both eighth and twelfth grade students failed to show increased performance between 2000 and 2005, with eighth graders also failing to increase from 1996 to 2000 and twelfth grade performance declining over that same period (Grigg et al.). However, in a world with increasingly level access to global exchanges and a declining influence of physical proximity, competition for occupations is increasingly international (Friedman, 2005). Such competition and the meaning it carries for American influence underscore the importance of evaluating the proficiency of American students relative to global peers and remaining cognizant that these comparisons may be more critical than national examinations.

A recent National Academies Press publication indicated the importance of U.S. optimization of knowledge-based resources in order to compete with the wage structure advantages of other nations (NASNAEIM, 2007). Also acknowledged in this text was the frequent public underestimation of the importance of science, technology, and mathematics, even as U.S. K-12 schools seem less able to interest and motivate students in science, technology, engineering, and math (STEM) subjects. Moreover, U.S. colleges ranked poorly against many other nations in the number and proportion of bachelor's degrees awarded, with many of the students who opted out of these STEM majors among the most qualified college entrants (NASNAEIM). Further, an international assessment of 15-year-olds that attempts to move beyond the evaluation of student ability to reproduce learned content to the determination of student proficiency in understanding and applying that content indicated substantial decreases in U.S. student performance relative to world counterparts (OECD, 2007). In 2006 PISA assessments, U.S. student science performance was below the OECD average, ranking between 18th and 25th among the 30 OECD countries in the analysis.[1] American student mathematics results were also below the OECD average and positioned the U.S. between 24th and 26th among the 30 OECD countries. In addition, U.S. mathematics performance declined from 2003 to 2006 even while most countries performed at the level of their 2003 results and a few even improved upon their earlier performances (OECD).

More troubling than these international data alone is their interpretation within the timeframe of the assessment; these results, specifically PISA, represent the state of students who are nearing the end of their compulsory education and rapidly closing in on critical decisions regarding continuation in the study of mathematics and science. In the context of global economic competition and with the U.S. dependent upon a workforce of competent STEM majors, providing a context for developing engaged, lifelong learners with sufficient foundational knowledge to access and implement higher-level concepts is a vital endeavor. Toward this end, student engagement with school is arguably an important focus, and gaining an understanding of conceptualizations of the construct as well as its relationship to important outcomes, a critical task.

The Role of Student Engagement With School

Student engagement with school can be described as a commitment to, valuing of, and connection with the people, educational goals, and outcomes promoted by a school (Finn, 1989) and has emerged as foundational to school reform efforts (see Furlong & Christenson, 2008; NRCIM, 2004; Wigfield & Wentzel, 2007). As described by Newmann and colleagues, engagement is "... the student's psychological investment in and effort directed toward learning, understanding, or

mastering the knowledge, skills, or crafts that academic work is intended to promote" (1992, p. 12). Engagement is a multidimensional construct (Fredricks et al., 2004) with nearly every conceptualization involving a behavioral component, most an emotional/affective component,[2] and some including a cognitive component (Appleton, Christenson, & Furlong, 2008). Recent conceptualizations describe four subtypes: academic, behavioral, cognitive, and affective engagement (Appleton, Christenson, Kim, & Reschly, 2006; Furlong & Christenson, 2008; Sinclair, Christenson, Lehr, & Anderson, 2003).

Under the four-subtype conceptualization, academic engagement is indicated by efforts in academic tasks, including the accrual of the credits necessary for graduation. Behavioral engagement can be assessed using information such as attendance records, disciplinary data, and level of participation in routine and higher-level school-related activities. Cognitive engagement is indicated by data such as student perceived: relevance and challenge sufficiency of coursework, efficacy (e.g., competence), context-facilitated autonomy (e.g., influence or independence), knowledge and accessibility of learning strategies, shared value of education, and self-regulatory capacity (e.g., self-control). Affective engagement can be assessed using information such as perceived connections to supportive others in the school (Appleton et al., 2006). Student engagement is believed to beget increased engagement (Furrer, Skinner, Marchand, & Kindermann, 2006) with engagement itself related to desired outcomes such as differences in achievement (including grades), school motivation, and persistence in the face of challenging tasks (Furrer & Skinner, 2003; Goodenow, 1992, 1993; Lee & Smith, 1999).

Specifically, cognitive engagement, one of the foci of the current study, has been related to both personal goal orientation and investment in learning (Greene & Miller, 1996; Greene, Miller, Crowson, Duke, & Akey, 2004; Pokay & Blumenfeld, 1990) and through these relationships associated with academic achievement (Miller et al., 1996). Likewise, behavioral engagement (which merges academic and behavioral engagement of the four-subtype model) has been connected with improved achievement as indicated by measures such as standardized tests and grades (Connell & Wellborn, 1991; Marks, 2000). Despite the potential of student engagement as an indicator related to important educational outcomes and a target for timely intervention, conceptualizations that overlook the influence of context on engagement fall short of providing a thorough understanding of the construct.

Contextual Influences on Student Engagement

Embedding the idea and level of engagement solely within a student bypasses critical theory on the development and maintenance of motivated learners. Students are believed to have fundamental needs for self-determination (e.g., autonomy, influence), connections to meaningful others (relatedness), and competence (Baumeister & Leary, 1995; Ryan & Deci, 2000); therefore, they seek a context within which these needs are met. In learning, students navigate an amalgamation of contexts, involving critical systems of the home, school, peers, and community/neighborhood (Christenson & Anderson, 2002). In these experiences, the success with which a context meets fundamental student needs and the complementary interactions of contexts are of vital importance. Considerations of the " 'affordance value' of the context—or how the learning context facilitates or impedes child adaptation to challenges and demands of schooling" (p. 379) are both beneficial and necessary (Christenson & Anderson).

Connell and Wellborn (1991) proposed a theory that combined cognitive, social, and motivational theories to describe what compelled a student to attempt to engage with and master a given environment. This model described general motivation, explained the relations among the context, the self, and subsequent action and had important implications for education and specifically, student achievement. Differences in student experiences were theorized to result from interactions within the social context that determined how well that student perceived the environment to meet his/her fundamental needs of autonomy, competence, and relatedness. A simple model of this process would be: CONTEXT → SELF → ACTION → OUTCOME in which the action was defined as engagement versus disaffection (e.g., withdrawal) and the outcome included valued educational goals such as achievement.[3]

Likewise, Self-Determination Theory (SDT) conceptualizes a student as predisposed to attempt to integrate experiences into a comprehensive conception of self (Ryan, 1995; Ryan & Deci, 2000). Similar to the previous model, students would experience the many contexts they encounter as more or less conducive to meeting fundamental

needs and respond to valued educational outcomes accordingly.

These theories underlie and help explain the functioning of the student engagement construct. Contextual support for autonomy underlies self-regulation and behavioral engagement; structure in the context facilitates efficacious strategy, capacity (e.g., perceived ability), and control beliefs (e.g., internal vs. external locus of control), ensuing perceived competence and subsequent cognitive engagement; and a context of involvement facilitates a sense of relatedness and subsequent emotional engagement (affective engagement) (Connell & Wellborn, 1991). Student engagement with school provides an organizing heuristic, while these theories help explain the underlying processes and mechanisms of the student engagement construct.

What these underlying theories share in common is that while a student may require initial persuasion to attempt activities that are not intrinsically motivating, underlying processes can ensure continued motivation with those activities provided supports are available in the context. For example, with participation–identification theory, those supports may be in the form of high-quality instruction and success in school-related activities with initial participation begetting further participation (Finn, 1989). For self-determination or self-processes theory, those supports could be a sense of connection with the teacher, ownership with the activity, and successful outcomes (Connell & Wellborn, 1991; Ryan & Deci, 2000; Ryan, 1995; Skinner, Wellborn, & Connell, 1990). What ensues has the potential to be an upward spiral of motivated persistence and engagement or an opposite outcome of non-efficacy, detachment, and a lack of autonomy. The difference will depend, in large part, on the students' experiences and perceptions of those experiences.

Relevance of the Current Study

Motivational theories underscore the importance of understanding student experiences in classrooms and schools in order to better predict and influence academic and socio-emotional outcomes. Each of these underpinning theories as well as the umbrella construct of student engagement focus upon outcomes associated with an active student navigating an environment that is perceived as more or less conducive to meeting his or her fundamental needs. Yet, teachers, operating from their perceptions, assume a substantial role (via facilitating and structuring) in shaping these classroom environments. How closely do teacher perspectives align with student perspectives and if substantial discrepancies exist, how should teachers evaluate the extent to which the classroom and school context meets student fundamental needs?

Differences in Perceptions (Student, Teacher, and Observer)

Research on the alignment of student, teacher, and outside observer perspectives revealed some potentially important differences. With a relatively large sample of science classes, two sets of analyses utilizing school level variables failed to predict achievement while an experiential examination of the data revealed similarity between the views of adults in different roles (including as outside observers) yet substantial differences from student views (Wood, Lawrenz, Huffman, & Schultz, 2006). Research examining both ideal and actual perspectives of classroom environments revealed that differences between student and teacher perspectives were greatest when reflecting on the real classroom with teachers perceiving greater involvement, teacher support, innovation, order and organization, and rule clarity (Raviv, Raviv, & Reisel, 1990). Finally, science student perceptions have been shown to not only differ from teachers' but also to be more closely connected to achievement (Lawrenz, Huffman, & Robey, 2003).

Substantial differences exist between student and teacher perspectives in school environments and these perspectives differentially relate to achievement. In the current study, teacher and student data were gathered via self-report measures while an additional perspective was provided by outside observers. Each of these sources of engagement data are important to consider as they are often considered interchangeable, yet may not align as closely as assumed. These three sets of information enable comparisons of perspectives across reporters and instrumentation. The current study furthers engagement research by examining (across science and math classrooms) differences in perspectives related to student engagement between student, teacher, and observer groups and then by considering the results through the framework of student engagement theory.

Method

The data presented here were collected over three years as part of an evaluation of the Collaboratives for Excellence in Teacher Preparation (CETP) program that was funded by the National Science Foundation

(NSF) to improve the preparation of pre-K–12 science and mathematics teachers. Data were gathered from principals, teachers, and students across the nation. Teachers trained in CETP programs as well as those trained in other programs were included.

Sample

Data were gathered from 159 teachers and 1,663 students. Participants were from several different states and a commonwealth of the United States, including Arizona, Massachusetts, New Mexico, Oklahoma, Oregon, Texas, and Puerto Rico. Teachers in this study included 95 participants at the middle school or junior high level (59.7%) and 64 at the high school level (40.3%). Of responding teacher participants, 104 (65.4%) were female and 128 (80.5%) had less than five years of teaching experience. Student participants included 995 (59.9%) in Grades 6–8, 649 (39%) in Grades 9–12, and 19 (1.1%) students not indicating their grade level. Of these 1,663 participants, 31.2% of those responding spoke a language other than English in their home, 46.6% were male, and 9.3% had been in their school less than one month.

Measures[4]

Both students and teachers responded to self-report instruments. The following items were answered by both students and teachers with slight wording differences to appropriately address the respective respondent: *How often were you asked to do the following in this class?* (1) participate in whole-class discussion where the teacher talks less than the students; (2)write descriptions of your reasoning; (3) work on problems related to real world or practical issues; (4) do activities that allow you to collect information (data) and figure out what the information means (analysis); (5) make connections to other STEM and non-STEM fields; (6) determine how much you know about something; and *How often were the following true about your class?*; (7) you have a voice in decisions about class activities; and (8) new information is based on what you already know about the topic. The surveys were scaled with the following response options: "Never" (1), "Seldom" (2), "Occasionally" (3), and "Regularly" (4).

In addition to the self-report instruments, a classroom observation protocol (COP) was used. This COP is a criterion-referenced instrument for describing and rating classroom activities in K-16 STEM settings. To effectively and reliably use the instrument, the observer must have sufficient content knowledge and enough rating experience so that he or she understands the standards-based criteria underlying every item.

The COP also includes both high and low inference items. Coding instructional strategies and student engagement is what might be called a low-inference observational technique because the "behaviors to be observed are specifically prescribed and predetermined before the observation takes place" (Roberson, 1998, p. 3). The COP was constructed by representatives from all of the CETPs through the participatory Core evaluation. Items were created as well as selected and reworked from several existing classroom observation (CO) instruments. Items selected were those that had been shown to be related to standards-based instruction and positive student outcomes. Sources providing these instruments included the Arizona Collaborative for Excellence in Teacher Preparation (Sawada et al., 2000); the Constructing Physics Understanding Evaluation project (Huffman & Michlin, 2001); Evaluation of the Long Term Effect of Teacher Enhancement project (Horizon Research, Inc., 1999; Lawrenz, Huffman, & Lavoie 2001); and the Systemic Initiatives Evaluation project (Statewide Systemic Initiatives Evaluation, 2000).

While the self-report items and COP were used to measure student levels of engagement, these measures examine different subtypes of engagement. The self-report items evaluate cognitive engagement and are consistent with the perspective that considers student interactions with the context as the conduit for perceived support and subsequent engagement (Connell & Wellborn, 1991; Ryan & Deci, 2000). A key consideration for later engagement under this conceptualization is the alignment between a student's perspective of the context and the facilitators of engagement school staff believe embedded within that environment. In contrast, the COP evaluates academic engagement in that the observer rates, across five-minute intervals, the percentage of students displaying on-task and involved actions relevant to the academic tasks of classroom instruction. The COP observer provided a score of one, two, or three for classroom percentages of engaged behavior depending upon whether *20% or less of students are engaged—1*, *between 20 to 80% of students are engaged—2*, or *80% or more of the students are engaged—3*. The values of these ratings across a 60–90-minute period (12 to 18 ratings) were then averaged to provide a mean level of observed engagement for that classroom.

Analysis Logic and Procedures

Several analyses were undertaken in this study to attempt to answer posited research questions. Initially, paired-sample *t*-tests were utilized to determine the similarity of teacher and student responses to comparable cognitive engagement self-report items. Cohen's *d* was calculated to examine the magnitude of student and teacher perceptual differences (Cohen, 1988). Internal consistency calculations were conducted using coefficient alpha to examine inter-item relationships for both student and teacher survey instruments, respectively. Finally, to consider the relationship of academic engagement observation protocol values and cognitive engagement teacher perceptions with student perceptions, a multi-level regression model was constructed and tested. Hierarchical Linear Modeling (HLM) analyses were used to account for variation both within and between classrooms. Conceptually, HLM was used to determine how well COP observed engagement (MeanEng) and teacher responses to engagement items (TeachEng) would predict student responses to engagement items (StEng). Both the teacher and student responses to engagement items resulted in coefficient alpha values (teacher: $r_\alpha = .66$ and student: $r_\alpha = .71$) that suggested sufficient internal consistency and supported the subsequent use of separate means across the items for teachers and students, respectively. Specifically, the HLM analyses used the variables of mean COP measured engagement and mean teacher-reported engagement to predict mean student-reported engagement.

Results

Sixteen paired *t*-tests and Cohen's *d* effect size estimates were used to examine differences between student and teacher perceptions of cognitive engagement across science and math classrooms. A Bonferroni correction was used to adjust for the potentially inflated experiment-wise alpha level resulting from the use of numerous *t*-tests. With the Bonferroni-corrected alpha set at $p < .003$ (i.e., .05/16), 15 of 16 *t*-tests were significant at $p < .001$. In every significant result, the student-indicated frequency of an event happening in the math or science classroom was less than the frequency indicated by teachers. The one non-significant finding involved the frequency of data collection and analysis in the math classroom. Sample sizes, means, standard deviations, and results of statistical tests are depicted in Table 1.

To further examine student and teacher perspectives and elucidate comparisons across math and science classrooms, significant mean differences were represented graphically. Effect sizes were calculated based upon Cohen's *d* formula for independent means and pooled standard deviations and these effect sizes were depicted graphically in Figure 1 (Cohen, 1988). The greatest effect sizes between student and teacher perspectives *that were also similar in magnitude across math and science classrooms* involved the frequency of: connections to STEM and non-STEM fields, writing about why you think something, and whole class discussions. The *smallest* effect sizes between student and teacher perspectives occurred with the frequency of: having a voice in decisions about class activities, collecting and analyzing information, and determining how much you know (although this result was only found in the math classroom). Finally, the *largest* differences in perspective, each nearly one SD, both occurred in the math classroom and dealt with the frequency of real world problems and information based on previous knowledge. These results can be found in Figure 1.

In examining differences between mathematics and science classrooms, the discrepancies in the magnitude of student-teacher perceptual differences were greatest[5] on items querying: problems related to real world or practical issues ($d_{diff} = .38$), student determination of their knowledge ($d_{diff} = -.20$), and connections between new information and prior knowledge ($d_{diff} = .17$). As indicated by the positive or negative value after subtracting the science classroom student–teacher effect size difference from the mathematics classroom difference, the first and third differences indicate greater teacher–student discrepancies in the mathematics classrooms, while the second indicated a greater discrepancy in the science classrooms.

The second research question asked whether third-party observations (using COP data) of academic engagement or teacher survey responses on cognitive engagement better predicted student survey responses on their levels of cognitive engagement. Distributional algorithms, as suggested by Bliss (1967), were used to examine the appropriateness of the data for use in an HLM. Both level-two predictor variables and the dependent variable resulted in appropriate skewness and kurtosis values less than |1.0| with MeanEng at −.908 and .024, TeachEng at −.754 and .420, and StEng equal to −.300 and −.204, respectively. Given these descriptive results, the data were considered

Table 1

Perceived Cognitive Engagement Differences in Mathematics and Science Classes

Item	Mathematics			Science		
	Students	Teachers		Students	Teachers	
	Mean (*SD*)	Mean (*SD*)	*N*	Mean (*SD*)	Mean (*SD*)	*N*
How often do students have a voice in decisions about class activities?[*,†]	2.53 (1.025)	2.71 (.770)	733	2.67 (.997)	2.80 (.603)	893
How often do students determine how much they know about something?[*,†]	2.96 (.922)	3.18 (.851)	721	2.97 (.847)	3.34 (.778)	879
How often do students make connections to other fields of science, technology, engineering, and mathematics, (STEM) and non-STEM?[*,†]	2.23 (1.014)	2.90 (.840)	723	2.62 (.982)	3.25 (.647)	889
How often do students do activities that include data collection and analysis?[†]	2.71 (.975)	2.73 (.777)	733	3.26 (.836)	3.46 (.621)	879
How often do students work on problems related to real world or practical issues?[*,†]	2.62 (.998)	3.43 (.673)	722	2.81 (.924)	3.28 (.709)	891
How often do students write descriptions of their reasoning?[*,†]	2.15 (1.012)	2.69 (.817)	718	2.64 (.993)	3.15 (.716)	893
How often do students participate in whole-class discussions during which the teacher talks less than the students?[*,†]	2.27 (.965)	2.68 (.841)	740	2.38 (.922)	2.81 (.669)	899
How often is new information based on what students already know about the topic?[*,†]	2.87 (.915)	3.58 (.573)	735	2.85 (.872)	3.44 (.663)	891

* Significant at $p < .001$ for mathematics classrooms.
† Significant at $p < .001$ in science classrooms.

appropriate and HLM analyses conducted. Results of the HLM indicated that COP scores (MeanEng) were not a significant predictor of student responses ($\beta = .627$, $p < .174$), while teacher responses to engagement items (TeachEng) were ($\beta = .236$, $p < .001$) with both MeanEng and TeachEng in the model at the same time. The mathematical model and results of this analysis are depicted in Figure 2 and Table 2.

Discussion

This study examined data from students, teachers, and outside observers to determine the convergence of the perspectives of these three groups on the dynamic and multi-dimensional construct of student engagement with school. To the extent that observational or teacher-response data are predictive of student-reported engagement data, those data could be utilized in promoting student engagement. To the extent that these perspectives are incongruous, increased efforts may be needed to determine and utilize student perceptual data to complement the data of other respondents (e.g., teachers) and observers and to further both student engagement and student STEM achievement. Specifically, student perspectives of engagement can be systematically collected and examined at either the school (Wood et al., 2006) or course level (Marks,

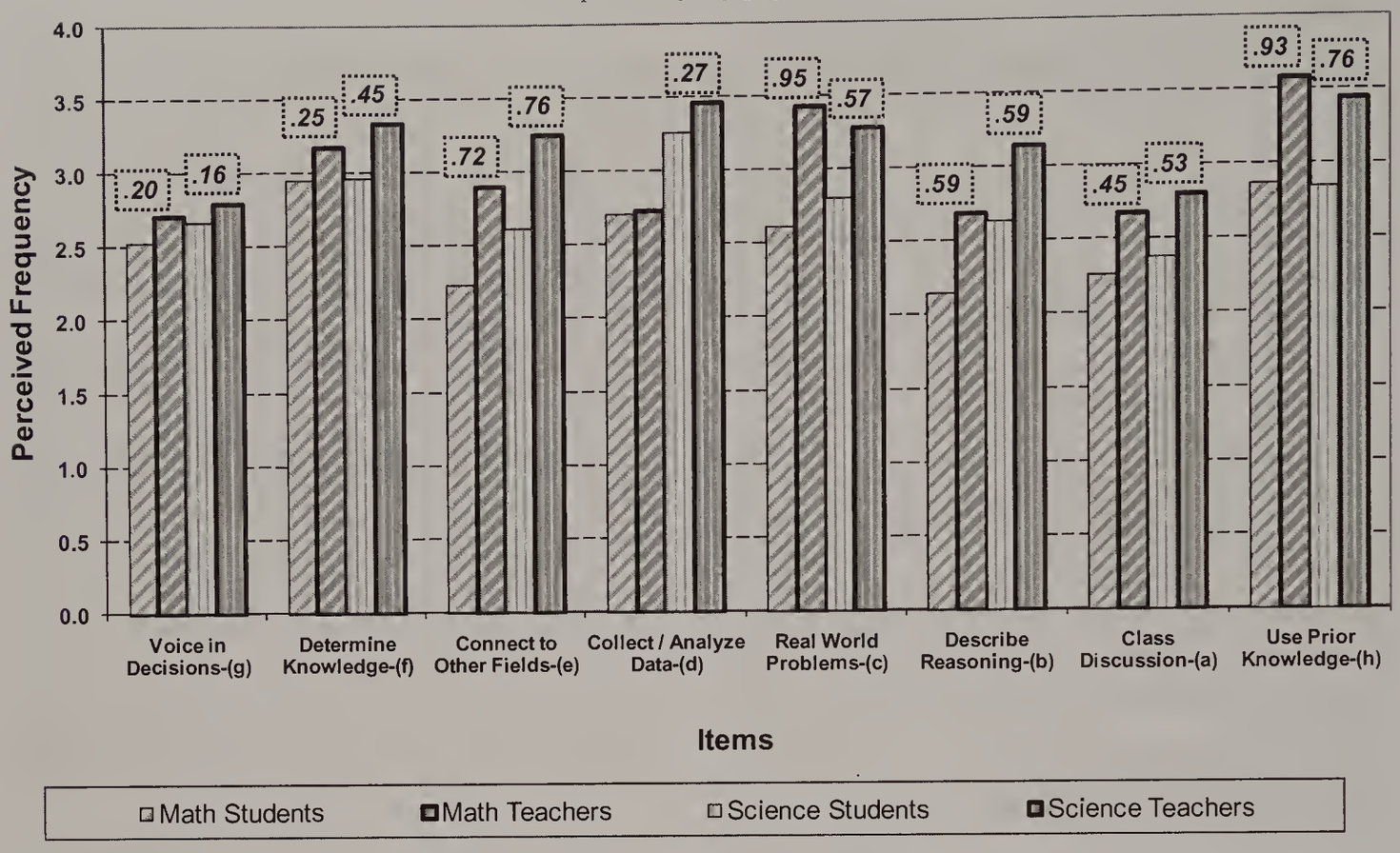

Figure 1. Effect sizes of differences between student and teacher perceived student cognitive engagement.[6]

Level 1: $Y_{ij} = \beta_0 + r_{ij}$

Level 2: $\beta_0 = \gamma_{00} + \gamma_{01}*(\text{MeanEng}) + \gamma_{02}*(\text{TeachEng}) + U_0$

Figure 2. HLM model.

2000), results compared with teacher perceptions and observations and appropriate adjustments made. To the extent these different engagement sources converge, one can have increased confidence in the engagement measurement. In contrast, discrepancies can provide insights into possible areas of intervention. For instance, teacher perceptions of engagement supported by observation data but not consistent with student perceptions could suggest student compliance without active interest and teacher-perceived relevance not shared by students.

The results of the current research extend prior work by suggesting the extent of the discrepancy between student and teacher perceptions of aspects of cognitive engagement across STEM disciplines. The consistency and magnitude of the differences between student and teacher perceptions supports research on both the importance of student perceptions and the frequent discrepancy between student and teacher perspectives of levels of student engagement (Lawrenz et al., 2003; Wood et al., 2006). The intent was to determine which types of data were predictive of engagement and to use those to help inform teaching practice.

Several student–teacher differences in perception were moderate to large (Cohen, 1988) across both mathematics and science classrooms. These differences in the perceived frequency of problems being related to real-world/practical issues, prior knowledge use, connections made to other STEM fields, and written descriptions of student reasoning demonstrate that, in these data, student–teacher perceptual discrepancies hold across science and mathematics. The items for which the largest student–teacher perceptual differences occurred in mathematics classrooms (*problems related to real-world/practical issues* and *use of prior knowledge*) underscore the value of examining how well teachers understand student perceptions of "real-world/practical" as well as the diversity and extent of students' prior knowledge. It appears that mathematics teachers' ideas of what is real world or practical are not the same as their students'.

Table 2
HLM Coefficients and Significance Tests

Fixed Effect	Coefficient	Standard Error	Approx. *t*-ratio	*d.f.*	*p* value
Intercept 1, β_0					
Intercept 2, γ_{00}	13.859	1.843	7.521	154	.000
MeanEng, γ_{01}	.627	.459	1.367	154	.174
TeachEng, γ_{02}	.236	.061	3.892	154	.000

Combining this inconsistency with the apparent discrepancy in what constitutes use of prior knowledge suggests that mathematics teachers could productively spend more class time discussing with students what their ideas of real world or practical issues are and how these relate to classroom mathematics. The mathematics standards of the National Council of Teachers of Mathematics suggest that mathematics classrooms provide instruction relevant to the students, but adult views of what is relevant may not match student views. The largest student–teacher differences occurring in science classrooms suggest science teachers should also consider what students believe is the use of prior knowledge and that they should try to better understand student perceptions of cross-STEM field references.

The second section of the initial research question examined *whether differences in alignment between student and teacher perceptions of student cognitive engagement existed between science and math classrooms.* Mathematics teachers differed from their students to a larger degree than science teachers in perceptions of how often problems were related to real-world/practical issues and how often new content referenced prior knowledge. In contrast, differences of a greater magnitude were found between science teachers and their students than mathematics teachers and their students in the frequency with which students determined their understanding of a topic. These differences align somewhat with the nature of science and mathematics classrooms but highlight the opportunities within each area for change and growth. Certainly, the PISA results suggest that more real-world problem-solving opportunities in mathematics would be beneficial, and this may also improve connections between students and teachers as understandings are co-constructed. Student determination of their understanding may be more aligned with teacher perceptions in mathematics due to the typically greater frequency (and awareness of the role) of correctable tasks in mathematics versus science classrooms. Perhaps science classrooms could benefit from self-assessment tasks to enable students to better understand their progression through the content. The extent to which the instructor is able to monitor student progress in content also has implications for student engagement as a sufficiently rigorous level of challenge associated with adequate support is central to improving engagement (Lee & Smith, 1999; NRCIM, 2004).

The second research question examined *whether student levels of cognitive engagement were better predicted by third-party observations of academic engagement or teacher perceptions of cognitive engagement.* In contrast to prior research which showed external observer ratings related to student achievement (Lawrenz et al., 2003), the HLM analyses indicated that the perceptions of outside observers were not a significant predictor of student-reported levels of student cognitive engagement, but that the perceptions of teachers did contribute significantly to the prediction of student-reported levels of engagement. Perhaps this finding was related to both the duration of the student-teacher relationship and the focus of the COP. Although the COP evaluation involved data from a single observation by an external viewer, the teacher had access to multiple class sessions in responding to the survey items. Moreover, despite the different and varied cultural experiences of teachers and students (Lawrenz et al.; Wood et al., 2009), the teacher self-report items asked for an estimation of student perceptions, while the COP required little in the way of inference and enabled the observer to base ratings on behaviors. These differences between COP and teacher-rated engagement are not without precedent. In fact, this finding would be

consistent with the conceptualizations of Fredricks et al. (2004) in the difference between subtypes of cognitive (high inference) and behavioral (low inference) engagement and underscore the importance of monitoring multiple subtypes of student engagement (Appleton et al., 2006).

In considering the insights these data provide for future efforts to quantify and intervene upon student engagement with school, several points must be made. Teachers may not be as good as students at perceiving student engagement, but do have input that relates. Moreover, academic engagement data, or observation by itself, may miss many aspects of high inference subtypes of student engagement (i.e., cognitive and affective) and, therefore, yield less precise estimates of the result of student interactions with their learning context, or student engagement. The elevation of student perception data should not obscure the value of observational data for guiding intervention. First, more frequent samples with finer scales may produce observation data more predictive of student perceptions of engagement. Second, a discrepancy between observational data and self-report data may assist future efforts to target areas to improve student engagement.

Strengths, Limitations, and Future Research

Strengths of the current study include the capacity to examine student engagement across the disciplines of mathematics and science, the perspectives of student, teacher, and outside observer, and the disparate data-gathering locations mentioned earlier. This broad range of these data increases the usefulness and generalizability of the results of this study.

Limitations include the coarseness of the scales used on the self-report instruments, which may not adequately capture the true range of feelings. In addition to the limitations of the COP discussed previously, there is the limited variation found within the COP data. While student and teacher response data allowed for responses ranging from one to four, COP engagement measures were limited to responses from one to three, with actual variation in the COP responses somewhat limited as well.

Differences in student, teacher, and observer alignment on student engagement may exist across different areas of mathematics and science and suggest an important area of future research. Also, future investigations could examine whether student–teacher differences occur as a function of teachers having better recall since they are involved in the planning of the classroom activities or may have records they can consult for more precise frequency estimations. Even so, it remains possible that events perceived in one manner by the teacher were simply interpreted or viewed differently by the students (Wood et al., 2009). Future research may also be able to parse the HLM-based predictions of student-reported engagement further by combining more precise proxies of English language proficiency with more complete demographic data across areas, such as gender, age, ethnicity, and socioeconomic status.

Conclusion

The three data sources considered in this study predicted only a small portion of student-reported cognitive engagement, although teacher perceptions were more predictive than observers' perceptions. However, the alignment of student and teacher perceptions is an important consideration when attempting to facilitate student engagement especially since teachers assume an influential role in shaping the instructional context. The student perspective is considered vital for engaging students (Furlong & Christenson, 2008) and instrumental for creating engaging contexts (Christenson & Anderson, 2002) and should be monitored. With mounting concerns regarding the international competitiveness of U.S. students, engaging lifelong learners in STEM disciplines is an essential endeavor. Future research could include refinement of data collection instruments, inclusion of more variables in the prediction analyses, separation of different types of science and mathematics classes and investigation of the effect of closer alignment between teacher and student perceptions.

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Authors' Notes

[1] Uses a 95% confidence interval to rank the performance of the countries' sample in science and mathematics.

[2] "Affective" is preferred to "psychological" as the latter term has been found to imply additional, unintended meaning among educators.

[3] Adapted from Skinner et al. (1990), p. 23.

[4] The 6–12 Student Survey—Form B, K–12 Teacher Survey, and COP, as well as development and use information are available at http://education.umn.edu/CAREI/CETP/default.html under "Instruments" and "Publications."

[5] All values expressed as the difference, between mathematics and science classrooms, in the student-teacher perception difference effect sizes shown in Figure 1.

[6] Parenthetical letters under data reference item text in method section. Only effect sizes for significant *t*-test values are displayed.

Urban Third Grade Teachers' Practices and Perceptions in Science Instruction with English Language Learners

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The study examined relationships among key domains of science instruction with English language learning (ELL) students based on teachers' perceptions of their classroom practices (i.e., what they think they do) and actual classroom practices (i.e., what they are observed doing). The four domains under investigation included: (1) teachers' knowledge of science content; (2) teaching practices to support scientific understanding; (3) teaching practices to support scientific inquiry; and (4) teaching practices to support English language development during science instruction. The study involved 38 third-grade teachers participating in the first-year implementation of a professional development intervention aimed at improving science and literacy achievement of ELL students in urban elementary schools. Based on teachers' self-reports, practices for understanding were related to practices for inquiry and practices for English language development. Based on classroom observations in the fall and spring, practices for understanding were related to practices for inquiry, practices for English language development, and teacher knowledge of science content. However, we found a weak to non-existent relationship between teachers' self-reports and observations of their practices.

As the school-age population in the United States becomes increasingly diverse, many teachers are not prepared to meet the learning needs of students from varied backgrounds. Teachers generally do not know how to work with students from diverse cultures or who speak a language other than English (Bryan & Atwater, 2002; National Center for Education Statistics, 1999). This problem is intensified for elementary school teachers who lack knowledge of science content and content-specific teaching strategies to promote students' scientific understanding and inquiry (Garet, Porter, Desimone, Birman, & Yoon, 2001; Kennedy, 1998). The problem is especially notable, as science has become part of high-stakes testing and accountability in the United States.

The research literature on teachers' practices in teaching science to English language learning (ELL) students is limited. While ELL students must learn science and English proficiency simultaneously, the research traditions and teacher education programs have kept these two issues largely separate (Lee, 2005). There is little research on (a) how key domains of science instruction with ELL students relate to one another and (b) how teachers' perceptions of their own teaching practices relate to their observed teaching practices in these domains. Without such knowledge, there is little hope for designing effective interventions to better serve ELL students and their teachers in the science classroom.

This study examined relationships among key domains of science instruction with ELL students based on third-grade teachers' survey-based self-reports of their classroom practices (i.e., what teachers say they do) and third-party observations of those practices (i.e., what teachers are observed doing in the classroom). The four domains included: (1) teachers' knowledge of science content; (2) teaching practices to support scientific understanding; (3) teaching practices to support scientific inquiry; and (4) teaching practices in science to support English language development. Specifically, the study examined the following research questions: (a) how were the four domains related to one another as measured by teachers' self-reports and classroom observations, respectively? and (b) how were teachers' perceptions (measured by self-reports) and teachers' practices (measured by classroom observations) related to one another?

The results of the study should inform and help refine reform-oriented professional development. If the four domains of teachers' knowledge and practices are related, then professional development can be based on strategic efforts that seek to incorporate the related domains concurrently. When these domains are treated in isolation from one another, teachers' professional growth may be impeded, leading to diminished quality of science instruction provided to all students, including ELL students.

Related Research

Teachers need to know the subject matter that they are required to teach and have content-specific teaching strategies (Kennedy, 1998). Teachers should help their students develop deep and complex understandings of science concepts, make connections among science concepts, and apply science concepts in explaining natural phenomena or real-world situations (National Research Council [NRC], 1996, 2007). Teachers should also recognize the role of prior knowledge, particularly students' misconceptions, in shaping students' understanding. Additionally, teachers should enable students to engage in scientific inquiry by recognizing problematic and incomplete information, making reasoned and well-supported arguments, and justifying solutions based on the evidence (NRC, 2000).

Classroom environments should be created by teachers of ELL students to promote development of both general and content-specific language (Wong-Fillmore & Snow, 2002). It is also important for teachers to take a developmental perspective on language and to create appropriate expectations about language development. In addition, teachers utilize this knowledge when teaching in academic content areas, such as science. As a result, teachers support students at all levels of English proficiency to learn academic language, give students at various levels opportunities to be engaged, and afford opportunities for students to display their learning in different modalities.

Relationships Among Domains of Science Instruction With ELL Students

Many teachers assume that ELL students must acquire English before learning science and are unaware of linguistic influences on science learning (Bryan & Atwater, 2002). However, an emerging literature highlights the integration of science with English proficiency for ELL students (Fathman & Crowther, 2006; Lee, 2005). For example, the acquisition of "science talk" includes more than just grammatical structures and lexicons (Lemke, 1990). Science talk includes knowledge of various subregisters representing specific disciplines. It also uses non-technical terms that have meanings unique to scientific contexts (e.g., matter, force, energy, space) but differ from their everyday use. Additionally, science talk requires ways of communicating specific to science disciplines, as students engage in science inquiry by formulating hypotheses, designing investigations, collecting and interpreting data, drawing conclusions, and communicating results (NRC, 2000).

ELL students can benefit greatly from hands-on and inquiry-based science instruction (Lee & Fradd, 1998; Rosebery, Warren, & Conant, 1992). Hands-on activities are less dependent on formal mastery of the language of instruction and, thus, reduce the linguistic burden on ELL students. Hands-on activities provide structured opportunities for developing English proficiency in the context of authentic communication about science. Hands-on activities based on natural phenomena are more accessible to students with limited science experience than is decontextualized textbook knowledge. Finally, hands-on activities promote students' communication of their understanding in a variety of formats, including gestural, oral, graphic, and textual.

Relationships Between Perceptions and Practices

There has been long-time interest in the relationship between teachers' self-reported practices (commonly referred to as "perceptions") and observed practices (commonly thought of as "real" practices). Studies indicate various relationships among different domains of classroom teaching. Fennema and Franke (1992) found that mathematics teachers' level of content knowledge was related to differences in teaching practices, such as the richness of the materials being taught and the depth of the classroom discussion. In studies of science and mathematics teaching, Morrell, Wainwright, and Flick (2004) explored the links between preservice teachers' perceptions of their practices as determined from interviews and their classroom practices as determined from observations. Although preservice teachers tended to be fairly accurate in describing what they did in the classroom, they sometimes overstated their instructional skills.

The literature also addresses the impact of professional development interventions on changes in teachers' perceptions and practices. Hart and Lee (2003) provided professional development to elementary

school teachers serving diverse student groups. Both quantitative and qualitative results indicated positive changes in teachers' perceptions and practices simultaneously. As teachers expressed a broader and more integrated conceptualization of literacy in science instruction, they integrated reading and writing in science instruction more systemically and extensively, and provided more effective linguistic scaffolding to enhance students' scientific understanding.

Method

Research Setting

This study was conducted in a large school district located in the southeastern United States. The district is composed of a linguistically and culturally diverse student population. During the 2004–2005 school year, the student population in the school district was 60% Hispanic, 28% Black (including Haitian and Caribbean Islanders), 10% White Non-Hispanic, and 2% Asian and Native American. Across the district, 72% of elementary students participated in free or reduced price lunch programs, and 24% were categorized as limited English proficient according to the state definition.

In May 2004, schools were invited to participate in a five-year research and development project based on three criteria: (1) percentage of ELL students (predominantly Spanish or Haitian Creole-speaking students) above the district mean at the elementary school level; (2) percentage of students on free or reduced price lunch programs above the district mean at the elementary school level; and (3) school grades of primarily C or D according to the state's accountability plan. Public schools in the state are assigned a letter grade (A, B, C, D, or F) based on a formula from the state's school accountability plan. At the time of this study, the school grade was based on student performance in reading and mathematics from Grades 3 through 5 and writing at Grade 4. These three criteria served as the boundary for selection of the schools to our larger project. Of the 206 elementary schools in the district, 33 schools met these criteria and 15 schools expressed a desire to participate in the research. Seven schools were assigned to the treatment group and eight schools to the comparison group.

Teacher Participants

For our school-wide initiative, we invited every third grade teacher in each treatment school to participate in our professional development intervention, described as follows. Of the 44 teachers who participated in the intervention, 38 teachers completed the entire school year and were included in this study. In terms of demographic backgrounds, 34 teachers were female and 4 male. Of these teachers, 19 identified themselves as Black, 9 as Hispanic, 5 as White Non-Hispanic, 2 as Haitian, 2 as Asian, and 1 "other." In addition, 32 teachers reported that English was their native language, 5 Spanish, and 1 Haitian Creole. In terms of professional backgrounds, 1 teacher reported having a specialist degree (beyond master's degree), 15 had master's degrees, and 22 had bachelor's degrees. For training in the area of English for Speakers of Other Languages (ESOL), 3 teachers reported having bachelor's or master's degrees in ESOL, 13 had endorsements through college coursework, 21 had endorsements through district training, 3 had endorsements that had been grandfathered in through long-time teaching experience, and 5 had no preparation. (Please note that of the 33 teachers who had training or endorsements in ESOL, several of these had multiple kinds of preparation, e.g., a bachelor's degree and an endorsement.)

Professional Development Intervention

Curriculum Units. Teachers used a Grade 3 curriculum that was closely aligned with the state science content standards and also followed recommendations by the National Science Education Standards (NRC, 1996). The three units for Grade 3 included Measurement, States of Matter, and Water Cycle and Weather. The teachers' guide for each unit begins with an explanation of (a) how to promote students' science inquiry and understanding of key science concepts and "big ideas" (patterns of change, systems, models, and relationships) to explain natural phenomena and (b) how to incorporate English language and literacy development as part of science instruction.

First, the student books support standards-based science learning that is focused on promoting students' science inquiry that is initially teacher-directed but gradually moves toward student-initiated. While the books emphasize key science concepts and big ideas, the complexity of science concepts increase as students move through the units. Teachers' guides provide content-specific teaching strategies for each lesson, including suggestions on how teachers may provide different levels of guidance and scaffolding. Teachers' guides also give suggestions for organizing and executing hands-on activities, as well as cautions about possible

problematic outcomes and how to respond to these. Additionally, teachers' guides provide science background information and explanations for the questions posed in the student books, with a particular emphasis on students' common misconceptions and learning difficulties.

Second, both student books and teachers' guides highlight activities and strategies to foster reading and writing during science instruction. For example, the units incorporate comprehension questions about inquiry activities, various language functions (e.g., describing, explaining, reporting, drawing conclusions) to promote science inquiry, and narrative vignettes and expository texts related to everyday experiences. The units also address the needs of ELL students by providing explicit guidance to promote their English proficiency. For example, language load at varying levels of English proficiency becomes increasingly more demanding as students progress from Grade 3 through 5. Key science terms in English, Spanish, and Haitian Creole are provided to support communication and comprehension. Multiple modes of communication and representation (gestural, oral, graphic, textual) are encouraged.

Teacher Workshops. During the first year of the project, third grade teachers in the treatment group attended five full-day workshops during regular school days that covered the content of each of the units, and also included data collection activities. First, the workshops focused on familiarizing teachers with the science content, hands-on activities, common student misconceptions, and potential learning difficulties in each lesson. Another area of science emphasis involved inquiry. Project personnel and teachers discussed the nature of science inquiry (NRC, 2000) and the teacher-explicit to student-initiated continuum to promote more student-centered and open-ended inquiry (Lee, 2002). Still another area of emphasis involved scientific reasoning of students and teachers' reflections on student reasoning.

Second, the workshops focused on incorporating English language and literacy development into specific science lessons. Project personnel described various strategies for developing students' reading and writing skills using examples in the Measurement unit. Project personnel also described how to provide linguistic scaffolding for ELL students. Additionally, teachers worked in small groups to incorporate ESOL strategies in selected lessons from the Water Cycle and Weather unit.

Instruments and Data Collection

The study used a teacher questionnaire and a classroom observation guideline. Although the teacher questionnaire was administered to the teachers in both the treatment and comparison schools, classroom observations were conducted only with the teachers in the treatment. As a result, this study reported the data from the treatment group.

Questionnaire. Based on relevant literature, our previous research (Hart & Lee, 2003; Lee, Hart, Cuevas, & Enders, 2004; Newmann, Secada, & Wehlage, 1995), and extensive pilot-testing in the fall of 2004, we developed a questionnaire to measure teachers' self-reported knowledge and practices in teaching science to ELL students. The questionnaire consisted of items that were grouped together to form scales that measure the four domains of teachers' perceptions of their knowledge and practices. Each scale used a 4-point rating system. Based on the teachers' responses in this study, internal consistency reliability estimates for the scales using Cronbach's alpha (α) ranged from .72 to .90, which were within an acceptable range.

The questionnaire included the following scales. First, the *teacher knowledge of science content scale* (SK) measures teachers' reported knowledge in teaching science topics at their grade level (α = .90). Second, *the practices for scientific understanding scale* (PU) measures teachers' reported practices in teaching science for understanding (α = .72). Third, *the practices for scientific inquiry scale* (PI) measures teachers' reported practices in teaching science for inquiry (α = .76). Finally, the *practices for English language development scale* (PELD) measures teachers' reported practices in using ESOL strategies or ESOL students' home languages to support English language and literacy in science instruction (α = .88).

To help teachers think about their classroom practices and guard against their responding quickly without thinking about these practices, the questionnaire items were framed in terms of specific time periods (such as "in the last month") and were focused on practices that teachers engaged in for sustained periods of time (such as "for at least 10 minutes"). The teachers completed the questionnaire for 30–45 minutes during the final teacher workshop in May 2005.

Classroom Observations. All third grade teachers were observed using scales adapted from our previous research on science instruction (Lee et al., 2004;

Newmann et al., 1995), and English language and literacy development in science instruction (Hart & Lee, 2003). Each observation scale used a 5-point rating system. In addition to quantitative ratings of teaching practices during specific lessons, observers produced extensive narrative field notes and justifications for their ratings.

The classroom observation guideline included the following four scales. First, the *teacher knowledge of science content scale* (SK) measures the extent to which the teacher's mastery of the science content of the lesson is accurate and comprehensive. Second, the *practices for scientific understanding scale* (PU) measures the extent to which students demonstrate a deep understanding of science. Third, the *practices for scientific inquiry scale* (PI) measures the extent to which students engage in scientific inquiry. Finally, the *practices for English language development scale* (PELD) measures the extent to which teachers support students' comprehension of academic content and development of English language. The *teacher knowledge of science content* and the *teacher support of English language development* scales focus on teacher practices, whereas the *scientific understanding* and *scientific inquiry* scales measure the instructional environment that the teacher and students jointly create.

Prior to the classroom observations in the fall of 2004, two project members participated in reliability training using the observation scales to rate videotaped lessons from our previous research. These project members continued training by observing lessons in real time and rating them on the scales until they established an inter-rater agreement of over 90%. Prior to conducting the second round of observations in the spring of 2005, the two members repeated the same training procedures using additional videotaped lessons from our previous research. Each third grade teacher was observed once in fall 2004 and once in spring 2005. The fall 2004 observations were conducted while teachers taught the Measurement unit, and the spring 2005 observations were conducted when most teachers taught the Water Cycle and Weather unit. Each observation typically lasted from 45 minutes to an hour.

Data Analysis

Of the 44 teachers who participated in our professional development intervention, the analysis for this study included only those 38 teachers who completed the entire school year. Thus, the analysis was based on 38 questionnaire responses in the spring of 2005 and 76 classroom observations in the fall of 2004 and the spring of 2005.

Table 1

Intercorrelations Among Domains of Teachers' Perceptions Using Questionnaire

	SK (*n*)	PU (*n*)	PI (*n*)
SK	—	—	—
PU	–.12 (38)	—	—
PI	.14 (37)	.59** (37)	—
PELD	–.14 (32)	.49** (32)	.29 (31)

Note. * $p < .05$. ** $p < .01$

Values in parentheses represent the number of teachers for each correlation.

Relationships Among Domains of Teachers' Perceptions. To measure the extent to which teachers reported their own knowledge of science content at their grade level, the questionnaire items used a 4-point rating system (1 = not knowledgeable; 2 = somewhat knowledgeable; 3 = knowledgeable; 4 = very knowledgeable). Similarly, to measure the extent to which teachers reported practices for scientific understanding, scientific inquiry, and English language development in their own teaching, the items used a 4-point rating system (1 = never or almost never; 2 = some lessons; 3 = most lessons; 4 = every lesson).

The questionnaire items were grouped together to form scales. The score for each scale was computed using the average of the responses to the items that comprised the scale. Use of the average item response, as opposed to the summated score, ensured that missing responses would not lead to a systematic negative bias of the scale scores. A scale score was computed only for those respondents who had valid responses for at least 75% of the items in the scale. If someone answered fewer than 75% of a scale's items, the respondent's scale score was set to be missing and omitted from that particular scale. Missing data for each scale are shown in Tables 1 and 4.

Relationships Among Domains of Teachers' Practices. The two observers followed standard conventions for the format of the field notes. Field notes were color-coded for episodes that illustrated reform-oriented practices for each of the four scales under

Table 2
Intercorrelations Among Domains of Teachers' Practices Using Fall Observations (n = 38)

	SK	PU	PI
Fall SK	—	—	—
Fall PU	.33*	—	—
Fall PI	–.04	.46**	—
Fall PELD	.29	.49**	–.05

Note. * $p < .05$. ** $p < .01$

Table 3
Intercorrelations Among Domains of Teachers' Practices Using Spring Observations (n = 38)

	SK	PU	PI
Spring SK	—	—	—
Spring PU	.48**	—	—
Spring PI	.22	.52**	—
Spring PELD	.21	.41**	–.07

Note. * $p < .05$. ** $p < .01$

investigation. For each scale in each lesson, a rating was given ranging from 1 (lowest) to 5 (highest) based on two criteria: (a) the frequency or intensity of reform-oriented practices and (b) the percentage of students who were engaged in such practices. In addition to the ratings, justifications were provided based on the evidence in the field notes of the lesson. The two observers and a third project member reviewed the entire set of observation notes to ensure reliability.

Relationships Between Teachers' Perceptions and Practices. The relationships among the four domains of teachers' perceptions, among the four domains of teachers' practices, and between teachers' perceptions and practices were examined using Pearson *r* correlations. For each set of analyses, both the coefficients and significance levels are reported. Scatterplots were scrutinized for possible linear trends among statistically significant correlated variables.

Results

Relationships Among Domains of Science Instruction with ELL Students

Relationships Among Domains of Teachers' Perceptions. The results of the intercorrelations among the questionnaire scale scores are displayed in Table 1. Although 38 teachers participated, there were missing data for some of the variables, causing the sample size to decrease. There were two statistically significant correlations. The practices for understanding scale is statistically significantly correlated with both the practices for inquiry ($r = .59$) and practices for English language development ($r = .49$) scales. Both correlations were positive and moderate in size.

Relationships Among Domains of Teachers' Practices. Table 2 shows the correlations among the fall observation variables. The results show three statistically significant correlations. The practices for understanding scale is related to science knowledge ($r = .33$); this is a positive, low correlation. Practices for understanding is also related to practices for inquiry ($r = .46$) and practices for English language development ($r = .49$); both are positive, moderate correlations.

Table 3 shows the correlations among the spring observation variables. Three statistically significant correlations are present, and these are the same correlations as those that were statistically significant in the fall data. The practices for understanding scale is related to science knowledge ($r = .48$), practices for inquiry ($r = .52$), and practices for English language development ($r = .41$); all of these are positive, moderate correlations.

Relationships Between Teachers' Perceptions and Practices

The results of the correlations between the teacher questionnaire scales and the comparable scales from the fall and spring observations are displayed in Table 4. There is one statistically significant correlation between the teachers' reported practices for inquiry on the questionnaire and the actual practices for inquiry observed in the fall ($r = .39$); this is a positive, fairly moderate correlation.

Discussion and Implications

Our most important finding is the key relationship between practices for understanding (PU) and the other domains (Research Question 1). Based on teachers' self-reports, the practices for understanding were related to practices for inquiry (PI) and practices for English language development (PELD). Additionally, based on classroom observations in the fall and spring, practices for understanding were related to practices for inquiry (PI), practices for English language development (PELD), and teacher knowledge of science

Table 4
Intercorrelations Between Teachers' Perceptions and Practices Using Both Questionnaire and Observations

Questionnaire	Fall Observations (*n*)	Spring Observations (*n*)
SK	–.001 (38)	–.17 (38)
PU	.09 (38)	.09 (38)
PI	.39* (37)	.24 (37)
PELD	–.17 (32)	–.03 (32)

Note. * $p < .05$. ** $p < .01$
Values in parentheses represent the number of teachers for each correlation.

content (SK). The results indicate that practices for understanding are related to the other practices *across* both sets of instruments and across times—an important replication.

Our second finding is a weak to non-existent relationship between teachers' self reports and our observations of their practices (Research Question 2). This finding could be attributed to several factors. One possible explanation is the difficulty of observing in a particular lesson what teachers reported to have taken place during a month's time (recall that many survey items asked how many times teachers engaged in an activity during the previous month for a minimum of 10 minutes). Future research could be conducted using more frequent or longer observations to increase reliability of classroom observation ratings. Another possible explanation is that teachers might perceive their own knowledge of science content and classroom practices differently than the goals of content knowledge and reform-oriented practices as measured by classroom observation ratings. Still another possible explanation is that our observers might have been using more stringent criteria than those the teachers used to rate themselves. Finally, it may be that the two instruments—self-report surveys and observation ratings—were tapping into different aspects of their respective constructs.

The results of the study contribute to the knowledge base on professional development for elementary school teachers of ELL students. While the study is correlational and thus cannot be used to draw causal inferences, our results offer initial insights into how connections may be present among key domains of teachers' knowledge and practices in science with ELL students. Our findings are consistent with Romberg, Carpenter, and Dremock's (2005) claim that *understanding matters*. In our study, understanding matters as a practice that is central to other reformed-oriented practices in the teaching of science with ELL students.

Results from analysis of the first year of this intervention provide guidance for our ongoing professional development and for others working with teachers in similar efforts. Professional development may focus on teaching practices that support student understanding of science. Professional development should then relate practices for science understanding to practices for science inquiry and practices for English language development of ELL students, as well as teachers' knowledge of science content. Our results suggest that these sets of teachers' knowledge and practices co-emerge, as related to understanding. We will further investigate these relationships and their practical implications within our larger project across grade levels and across years.

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Fundamental Fraction Knowledge of Preservice Elementary Teachers: A Cross-National Study in the United States and Taiwan

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The purpose of this paper is to show the similarities as well as the differences of fundamental fraction knowledge owned by preservice elementary teachers from the United States (N = 89) and Taiwan (N = 85). To this end, we examined and compared their performance on an instrument including 15 multiple-choice test items. The items were categorized into four different types of fundamental fraction constructs, including part–whole relationship, quotient, equivalence, and meanings of operations. Each item was embedded in the area, linear, or set model except for the items constructed out of the meaning of operations. Several items were featured with a pictorial illustration. Quantitative analysis showed that U.S. preservice teachers were significantly outperformed by their Taiwanese counterparts overall. The difference between the two groups was statistically significant on 12 of 15 items. Findings suggest that preservice elementary teachers from both countries need to be better prepared in their understanding of the meaning of fraction multiplication or division operations. Findings also suggest that U.S. preservice elementary teachers need to be more knowledgeable in dealing with fraction problems embedded in a linear model. Further research is suggested to study the issues raised from the findings.

International comparative studies provide a unique opportunity to understand the issues of mathematical learning and teaching from a broader perspective, to identify potential factors that contribute to the international differences, and to generalize insights into ways to improve the quality of mathematics education (Cai, 2000, 2004; International Commission of Mathematics Instruction [ICMI], 2000). For example, the results of the Video Studies of Teaching and the Curriculum Analysis by the Third International Mathematics and Science Study (TIMSS) conducted in 1999 have contributed to the increase in using Japanese Lesson Study as the basis of many professional development programs in the United States (Lewis, Perry, Hurd, & O'Connell, 2006), and worldwide interests in comparing the content and focus of mathematics textbooks across different countries on specific topic areas (Fan & Zhu, 2007).

While there is a long history of international comparative studies that have focused on the mathematics achievement of grade K–12 students, less attention has been placed on exploring possible contributing factors, such as teacher knowledge, which plays a critical role in providing quality instruction (Tatto, Schwille, Senk, Ingvarson, Peck, & Rowley, 2008). However, due to the growing body of research that supports the critical role teacher knowledge plays in providing quality instruction (Hill, Rowan, & Ball, 2005; Kahan, Cooper, & Bethea, 2003), there is a growing recognition of the importance of such a study (Zhou, Peverly, & Xin, 2006). For example, Kahan et al. (2003) found that preservice teachers' mathematics content knowledge influences their lesson planning and teaching. The next step is to develop a better understanding of the mathematics content knowledge possessed by the preservice elementary teachers in specific topic domains.

In this study, we investigated the similarities and differences in mathematics knowledge between U.S. and Taiwanese preservice elementary teachers. The most recent TIMSS, conducted in 2007, and the Programme for International Student Assessment (PISA), conducted in 2006, indicate that Taiwanese students had much higher level of mathematics achievement

than their American counterparts in a national representative sample of fourth graders, eighth graders, and 15-year-olds (Baldi, Jin, Skemer, Green, & Herget, 2007; Mullis, Martin, & Foy, 2008). The main goal of this study was to identify the possible root of such discrepancy in student performance by focusing on the mathematics knowledge of preservice elementary teachers.

The mathematics knowledge that we focused on is the fundamental knowledge of fractions, a critical component of elementary school mathematics. The National Mathematics Advisory Panel (2008) concludes that the lack of conceptual understanding and procedural fluency with fractions is a major obstacle for further progression in mathematics, including algebra. Studies done by Zhou et al. (2006) found that third grade Chinese teachers performed much better on the content knowledge of fractions measured in terms of concepts, computations, and word problems. This result is consistent with the results of comparative student mathematics achievement between China and the United States. However, fraction knowledge is vast and complex; simply knowing that U.S. teachers do not possess the same level of understanding of fractions as their Chinese counterparts does not provide guidance as to how and where mathematics educators might start addressing such deficiencies in the mathematics courses designed specifically for preservice elementary teachers. The present study seeks to make specific suggestions for improving mathematics programs for preservice teachers by exploring their understanding of fundamental fraction knowledge, such as the understanding of commonly used meanings of fractions, the judgment of equivalence, and the interpretation of meanings of fraction operations.

Teachers' Mathematics Knowledge

Subject-matter content knowledge, as proposed by Shulman (1986), has been universally considered as an essential attribute for effective teaching and successful learning. According to Shulman, subject-matter content knowledge encompasses knowledge of the subject-matter structure, which is composed of the substantive and syntactic structures of a discipline. Substantive knowledge refers to "a variety of ways in which the basic concepts and principles of the discipline are organized to incorporate its facts," and syntactic knowledge refers to "truth or falsehood, validity or invalidity, are established" (p. 9).

Recently, Ball, Thames, and Phelps (2008) expanded Shulman's subject-matter content knowledge into three subdomains: common content knowledge, specialized content knowledge, and horizon knowledge. Common content knowledge refers to mathematical knowledge and skills that are used in any setting, not necessarily in the setting of teaching. Specialized content knowledge, a central idea in the proposed model, refers to mathematical knowledge and skills needed uniquely by teachers. Examples of such knowledge include determining the validity and potential of nonstandard solution methods, and knowing the affordances and limitations of different types of diagrams in communicating mathematical ideas. Finally, horizon knowledge includes teachers' awareness of how the mathematical topics covered in previous years in schools are related to curriculum topics addressed in subsequent years in schools. In the present study, we investigated the subject matter content knowledge possessed by U.S. and Taiwanese preservice elementary teachers needed to introduce fraction concepts and operations—which we refer to as fundamental knowledge of fractions. This is a subset of common content knowledge and specialized content knowledge based on Ball and her colleagues' model.

During the past two decades, research has consistently revealed that U.S. preservice elementary teachers are weak in their knowledge of fractions (Azim, 1995; Ball, 1990a, 1990b; Graeber, Tirosh, & Glover, 1989; Simon, 1993; Tirosh, 2000; Tirosh & Graeber, 1990). For example, while working on the topic of fraction division, Ball (1990a) found that preservice elementary teachers often concentrated only on remembering rules and mastering standard procedures rather than demonstrating comprehensive understanding of mathematical ideas and procedures. In a series of studies conducted by Tirosh and her colleagues (e.g., Graeber et al.; Tirosh & Graeber), preservice teachers were found to determine the needed type of operations for a word problem based on whether a fraction was embedded in that problem. For example, preservice teachers tended to use division to solve the word problem: "The price of one bolt of silk fabric is \$12,000. What is the cost of $\frac{3}{4}$ of the bolt?" However, they used multiplication to solve the same word problem when the $\frac{3}{4}$ was replaced with a whole number. As argued by Tirosh and her

colleagues, this kind of misconception might be due to the idea that the dominant problem models recognized by many preservice teachers for the multiplication and division of whole numbers might mismatch their perceptions about fractions. Although the recognition of problem models has been considered a potential factor, it is imperative to acknowledge that few attempts have investigated preservice teachers' paradigmatic knowledge of fractions. Paradigmatic knowledge focuses on "mathematical models or mathematical structures that are universal and context-free" (Chapman, 2006, p. 216). Our understanding about preservice elementary teachers, as it relates to fractions, remains fragmented.

Teachers' mathematics knowledge is often rooted in their own grade K–16 education. Mathematics courses specially designed for preservice teachers provide an opportunity to strengthen their knowledge (Kulm, 2008). As pointed out by the authors of the Mathematical Education of Teachers (Conference Board of the Mathematical Sciences [CBMS], 2001),

> the key to turning even poorly prepared preservice elementary teachers into mathematical thinkers is to work from what they *do* know—the mathematical ideas they hold, the skills they possess, and the contexts in which these are understood—so they can move from where they are to where they need to go. (p. 17)

To this end, our study contributes to the need for specific information about what knowledge of fractions preservice elementary teachers possess to better design mathematics courses for preservice teachers.

Cross-National Studies

From the most recent TIMSS report, we find a substantial gap in student mathematics achievement between the United States and the five eastern Asian countries including Taiwan, Republic of Korea, Singapore, Japan, and China (Hong Kong) (Mullis et al., 2008). The results of international ranking on the mathematics knowledge of middle and high school mathematics teachers are similar to those on the mathematics achievement of students (Schmidt et al., 2007). However, it is still unclear how similar or different the mathematics knowledge of elementary teachers is. In addition, we need to expand our research attention from establishing an international ranking to exploring specific patterns and insights of mathematics knowledge that contribute to the potential difference between U.S. and Asian teachers.

Using Shulman's framework, Zhou et al. (2006) developed a written instrument to compare the subject matter content knowledge, pedagogical content knowledge, and general pedagogy knowledge between 90 U.S. and 70 Chinese third grade public school teachers. The subject matter content knowledge section of the assessment includes three parts: concepts (max: eight points), calculation (max: three points), and word problems (max: three points). Chinese teachers performed much better than their U.S. counterparts on all three parts, but the difference between two groups for basic fraction concepts is not as wide as that for computations and word problems. The focus of basic concepts is on teachers' understanding of the comparison of fraction unit and value, the equivalent fractions, and the reduction of fractions to simplest terms. However, the analysis reported only the mean percentage of the total score, rather than breaking it down into each of the concepts. It still does not offer much information about the concepts that cause the most trouble for U.S. third grade teachers in the study. In the present study, we expanded the range of fundamental fraction concepts to also include meanings and models of fractions and operations. We sought to identify the patterns of responses on these fundamental concepts of fractions.

Another type of fundamental concept we included in our study is the role of models (e.g., area, linear, or set) and the effect of the availability of pictorial representations on U.S. teachers' mathematics performances. The use of models and pictorial representations is a common theme in elementary math textbooks in general, and is particularly prominent in fraction instruction (Reys, Lindquist, Lambdin, & Smith, 2007). In earlier studies about mathematical thinking, Cai (2000, 2004) found that U.S. students were much more likely than Chinese students to use more guess-and-check and pictorial strategies. Later, Cai (2005) found that the same patterns existed in teachers' tendency to use more concrete, pictorial representations than their Chinese counterparts to generate data as well as foster students' conceptual understanding. It would be interesting to know how deeply this different tendency is rooted. Rather than replicating the comparison on the problem-solving strategies, the present study sought to determine

whether U.S. preservice elementary teachers could perform better than their Asian counterparts on more pictorial and concrete but less symbolic formatted problems.

Design and Method

The present study was designed to explore and compare the fundamental fraction knowledge held by preservice elementary teachers from the United States and Taiwan. To this end, we examined and compared their performance on various fraction problems. The following subsections detail the research method.

Research Questions

The theoretical and empirical literature discussed in earlier sections led to the following specific research questions:

1. Do U.S. and Taiwanese preservice teachers differ in their performance on the assessment for fundamental fraction knowledge?
2. How do U.S. and Taiwanese preservice teachers respond similarly or differently to different types of fundamental fraction constructs?
3. Do different types of models have similar effects on both U.S. and Taiwanese preservice teachers?
4. Does the existence (or lack) of pictorial illustrations have similar effects on both U.S. and Taiwanese preservice teachers?

Participants

To answer the research questions, we designed a cross-national study with 174 preservice elementary teachers: 89 from the United States and 85 from Taiwan. The purposive sampling was adopted to determine the participants (Leedy & Ormrod, 2005). Generally speaking, the education system in the United States is more localized and heterogeneous than that in Taiwan. On the U.S. site, therefore, to reflect the typical diversity better, the participants were selected from two institutions, including a national research-oriented institution and a regional teaching-oriented institution, located in different geographic areas. On the Taiwanese site, the participants were selected from a traditional teacher education university. It is worth noticing that the majority of preservice elementary teachers in Taiwan have their own content concentration like those of middle and secondary school majors in the United States. Therefore, mathematics and science education majors in Taiwan were excluded to ensure that their content strength did not contribute to a potential difference in such a small-scale study.

Instruments and Measures

All participants of this study took a paper-and-pencil assessment with 15 multiple-choice items that covered three main types of fundamental fraction knowledge: meanings of fractions, equivalence (fraction comparison), and meanings of fraction operations. Because the meaning of fractions is the foundation of all fraction concepts, we decided to focus on two different constructs: part–whole relationship and quotient. In the interpretation of part–whole relationship, $\frac{3}{4}$ means considering three parts of a whole that has been partitioned into four equal parts. The quotient meaning of $\frac{3}{4}$ arises from a portioning situation such as sharing three candy bars among four friends. These two constructs were chosen because they are the two most commonly used fraction meanings when introducing fractions in the United States and Taiwan (Lamon, 2007; Ministry of Education, 1998; Reys et al., 2007). So together, there are four different types of fundamental fraction constructs in this assessment. We included items that are most likely to be represented with different models, including area, linear, and set models, so that we can compare how preservice teachers from the United States and Taiwan respond to these different types of fundamental fraction constructs and models. We did not categorize the items for the meanings of operation into any particular models, because there is no strong connection between the types of models and these items' questions that ask for transforming symbolic expressions into a story problem or pictorial illustration.

Furthermore, we developed some items in pairs to make an appropriate comparison. Two pairs of items—Items #2 and #6 as well as #8 and #9—have the same fraction construct, but only items #2 and #9 have a pictorial illustration as part of the problem statement. Items #3 and #5 are embedded in the same fraction construct, but have different contexts that tend to lead to different representation models: area versus linear. Table 1 provides a summary of the 15 test items embedded in the described different types of fundamental fraction constructs, models, and the presence of pictorial illustrations.

Items #13, #14, and #15, focusing on the meanings of fraction operations, asked preservice teachers to identify the story problems or pictorial representations that would (or would not) match the given expression

Table 1
The Types of Fundamental Fraction Constructs and Models 15-Item Instrument

Constructs	Models	Item Numbers
Part–whole relationship	Area	#4[p], #7[p]
	Linear	#8[p], #9,
	Set	#2[p], #6, #12
Quotient	Area	#5
	Linear	#3
Equivalence (fraction comparison)	Area	#1, #11[p]
	Set	#10
Meanings of operations	#13, #14[p], #15	

Note. [p] A problem includes a pictorial illustration.

in different operations—subtraction, multiplication, and division. In U.S. elementary mathematics curriculum, the expression $a \times b$ is interpreted as "a groups of b," but in Taiwanese curriculum, the expression $a \times b$ is interpreted as "b groups of a." So both expressions are included in #14 (see Table 1) when choosing the pictorial representations for modeling multiplication. Similarly, acknowledging the inverse relationship between the multiplication and division operations, we included the equivalent expressions in #15 (see further discussion) to match the story problems using those operations. To accommodate double expressions in items #14 and #15 in multiple-choice format, both were stated in negative format. We believe that it is important for future teachers to have a solid understanding of these equivalences, and we would like to know the degree of the flexibility and connectivity in their reasoning.

15. Which of the following cannot be solved by either $8\frac{2}{3} \div 4$ or $8\frac{2}{3} \times \frac{1}{4}$?

(a) John's flowerbed is $8\frac{2}{3}$ square feet. He wants to plant pansies for $\frac{1}{4}$ of the flowerbed. What is the area of his flowerbed that will be planted by pansies?

(b) Jim played $8\frac{2}{3}$ hours of video games in 4 days. What is the average hours he spent on video games each day?

(c) May traveled $8\frac{2}{3}$ miles in $\frac{1}{4}$ hour. Maintaining the same speed, how long can she travel in one hour?

(d) All of the above.

(e) None of the above. Correct Answer: ___

The first 10 items of the test instrument were originally written in Chinese by the third author, and the items on operations were written in English by the second author. The translation to the other language was done first by the original authors of these items, and then reviewed/revised by the first author. All three authors are native Chinese speakers. The resulting Cronbach's alpha for the total scale is .731.

Data Collection and Analysis

In a natural classroom setting of mathematics methods classes, before entering the topic of fractions, participants answered the multiple-choice instrument. Since the *t*-test provides accurate estimates of statistical significance under various conditions for causal-comparative research, this technique was used to make the comparison of differences between overall means (Gall, Borg, & Gall, 1996). The correct response percentages for each item and for the whole test for U.S. preservice elementary school teachers were calculated and compared with those of their Taiwanese counterparts. They were then analyzed with various statistical techniques—paired and unpaired *t*-tests, one-way analysis of variance (ANOVA), and Scheffe *post hoc* test—to answer each of the research questions listed earlier.

Results

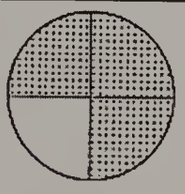
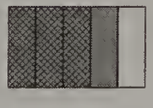
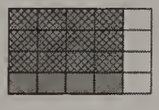
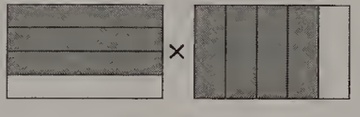
As indicated previously, the aim of this study was to investigate the similarity and difference in performance patterns between U.S. and Taiwanese preservice elementary school teachers' fundamental knowledge of fractions. In this section, we report on the two groups' overall performance, comparison with respect to different types of main subconcepts, models, and whether pictorial illustration was included in the problem statements. The following sections detail the results.

Comparison of Overall Performance

Overall, Taiwanese preservice teachers significantly outperformed their U.S. counterparts as indicated by the *t*-test ($\alpha = .05$). On a 15-point scale, the U.S. preservice group had a mean score of 8.8 (58.9%) with a standard deviation of 2.5 (16.3%). For their Taiwanese counterparts, the mean score was 12.6 (84.3%) with a standard deviation of 1.8 (11.9%). When comparing the performance of the two groups of preservice teachers on individual problems, we found that the difference was statistically significant

Table 2

Items #7, #11, and #14: Problem Statement and Correct Percentage for Each Group

Problem Statement	United States (%)	Taiwan (%)
7. Using the picture on the right, divide the shaded portion into six equal parts. Highlight $\frac{1}{6}$ of the shaded part. What portion of the circle was highlighted?  (a) $\frac{1}{6}$ (b) $\frac{1}{7}$ (c) $\frac{1}{8}$ (d) $\frac{3}{4}$ (e) None of the above.	76.4	87.1
11. In the two identical rectangles, which one has more shaded area? (A) (B) (a) (A) has more. Because it looks bigger. (b) (A) has more. Because $\frac{3}{10} > \frac{3}{9}$ (c) The same because they both have three pieces. (d) (B) has more. Because $\frac{3}{10} < \frac{3}{9}$ (e) None of the above.	84.3	85.9
14. Which of the following pictures cannot be used to model $\frac{3}{4} \times \frac{4}{5}$ or $\frac{4}{5} \times \frac{3}{4}$? (a)  (b)  (c)  (d) All of the above (e) None of the above	19.1	23.5

($\alpha = .05$) on 12 of 15 items. The three items that reveal no statistically significant difference ($\alpha = .05$) were items #7 (part-whole, area), #11 (equivalence, area), and #14 (meaning of operations). Table 2 includes these three problems.

The results for the three items with no significant difference were caused by two different performance patterns. One pattern showed that the U.S. preservice teachers had high performance on items #7 and #11, which are embedded in an area model, as did their Taiwanese counterparts; the other pattern showed that both groups had low performance on item #14, which is used to assess the understanding for the meaning of operations. Both items #7 and #11 were answered correctly by over 75% of the preservice teachers. In contrast, item #14 was the hardest item on the test for both U.S. and Taiwanese preservice teachers. The negative nature of item #14, choosing the model that would not work instead of the model that would work, might have misled some preservice elementary teachers. However, a follow-up discussion of this item revealed gaps in preservice elementary teachers' understanding of fraction operations. Many preservice elementary teachers in Taiwan and the United States chose (a) as the answer, because they saw that the whole for $\frac{4}{5}$ was a rectangle containing 5 parts, while the whole for $\frac{3}{4}$ was a smaller rectangle containing four parts. They believed that the whole for $\frac{4}{5}$ and $\frac{3}{4}$ should be drawn to the same size

as in (c). These preservice elementary teachers focused on just representing each fraction number in the number sentence but ignored the embedded operation. For them, the pictorial model for $\frac{3}{4}+\frac{4}{5}$ would look exactly the same as $\frac{3}{4}\times\frac{4}{5}$, except having a different operation sign in the middle. This type of modeling does not contribute to the conceptualization of possible solution strategies. This may be a problematic area that needs additional attention from both countries. Notice also that the problem statements for both #7 and #11 contain pictorial illustrations. The effect of the existence of pictorial illustrations will be examined more extensively in the later section.

The result indicating that item #14 was the hardest problem for both groups motivated us to look for other similarities in their performance. We then arranged all the items from the lowest to the highest percentage of correct responses for each group, as shown in Table 3. The U.S. data fell somewhat in three main clusters: those items answered correctly by more than 75%, between 50% and 75%, and below 40% of the preservice teachers. The Taiwan data are all close to one other, with all but three items below 80%. Generally speaking, the rankings for both groups are quite similar. For example, in addition to item #14, both groups of preservice teachers found items #12 and #15 to be quite challenging. Item #12 is a multi-step word problem. Item #15 asks preservice teachers to determine, among four story problems, which one cannot be modeled by either $8\frac{2}{3}\div 4$ or $8\frac{2}{3}\times\frac{1}{4}$. This indicates that, generally speaking, preservice teachers responded similarity to the conceptual complexity of the problems.

Similar patterns can be seen on items that appear to be easy to both groups. For example, item #1 (equivalence, area region) was the second highest scored item for both groups, along with #13 (meanings of operation) close behind. Item #1 assesses preservice teachers' knowledge of the critical role unit plays when comparing two fraction quantities. Item #13 asks preservice teachers to select a word problem matching the expression $6\frac{1}{2}-\frac{2}{3}$. Both appeared to be relatively easy for preservice teachers from the United States and Taiwan.

Table 3
Correct Percentage of Responses in an Ascending Order for Each Group

Items	United States (%)	Items	Taiwan (%)
#11	84.3	#9	98.8
#1	83.1	#1	95.3
#13^	83.1	#4^	95.3
#5	76.4	#13^	95.3
#7^	76.4	#10	94.1
#4	75.3	#2	91.8
#9	64.0	#5	90.6
#2	62.9	#7	87.1
#10	61.8	#8	85.9
#6	53.9	#11^	85.9
#12	40.4	#3	83.5
#3	36.0	#6^	83.5
#8	33.7	#15	78.8
#15^	33.7	#12	74.1
#14	19.1	#14	23.5
Average	58.9	Average	84.3

Note. ^ indicate the same % as the previous item.

Comparison of Performance With Respect to Types of Fundamental Fraction Constructs

In the second analysis, we compared the group performance with respect to different types of fundamental fraction constructs: two meanings of fractions (part-whole and quotient), equivalence (comparison), and meanings of operations. Table 4 shows the percentage of the mean scores of the U.S. and Taiwanese preservice teachers for each of these constructs.

We first performed and then conducted the one-way ANOVA to determine if the differences in the mean scores were statistically significant. The results revealed by SPSS reject the null hypothesis for both U.S. and Taiwan data (α = .05). We then used the Scheffe *post hoc* analysis to identify the source of the significant differences. The results of the Scheffe *post hoc* analysis are included in Tables 5 and 6. On the Taiwan data, the only significant difference was

Table 4
Correct Percentages with Respect to Each Type of Constructs

Construct	United States (%)	Taiwan (%)
Part–whole relationship #2, #4, #6, #7, #8, #9, #12	58.1	88.1
Quotient #3, #5	56.2	87.1
Equivalence #1, #10, #11	76.4	91.8
Meanings of operations #13, #14, #15	45.3	65.9

illustrated in the difference between the meanings of operations and the other three constructs. Therefore, we can conclude that meaning of operations was the hardest type of fundamental construct for Taiwanese preservice teachers. The pattern on the U.S. side was not quite as clear. There was a significant difference between equivalence and all the other constructs, which confirms that equivalence was the easiest type for U.S. preservice teachers. There was also a significant difference between part-whole relationship and meanings of operations. However, the differences between part–whole relationship and quotient, as well as quotient and operation, were not significant. Nevertheless, it is safe to say that preservice teachers from both countries found items on meanings of operations to be challenging.

When examining closely for the three items of operations (#13, #14, and #15), we found that both groups responded similarly to all three items. Recall the fact that item #14 was the most challenging for both groups. Item #13 asked preservice teachers to select a word problem matching the expression: $6\frac{1}{2}-\frac{2}{3}$, which appeared to be relatively easy for preservice teachers from both the United States and Taiwan—83.1% and 95.3%, respectively, chose the correct answer. Both groups also found #15 to be challenging: 33.7% of U.S. preservice teachers and 78.8% of Taiwanese preservice teachers answered it correctly.

While both items #13 and #15 asked preservice teachers to connect story problems with given expressions, item #15 was more symbolically and semantically complicated because (a) it contains two equivalent symbolical expressions and (b) it has a negative statement in its question. Furthermore, the performance difference could be caused by the complexity of the needed cognitive processes between addition/subtraction and multiplication/division operations. The conceptualization of fraction multiplication and division requires a shift of units, while the same unit is maintained during addition and subtraction.

Comparison of Performance With Respect to Different Problem Models

In the third analysis, we compared the group performance with respect to different problem models: area, linear, and set models. Table 7 shows the correct percentage of U.S. and Taiwanese preservice teachers for each of these models.

On the U.S. side, it appeared that items with an area model were the easiest for U.S. preservice teachers, followed by the set and linear models. On the Taiwan side, the mean differences were not as great. We then conducted the ANOVA and Scheffe *post hoc* test to further test these observations. The results indicated that pair-wise differences among area, set, and linear models are all statistically different ($\alpha = .05$) on the U.S. data. However, none of them was significant on the Taiwan side. Therefore, while model appears to be a factor influencing U.S. preservice teachers' performance, it did not appear to be an influencing factor on Taiwanese preservice teachers' performance.

To examine the differentiated effect further, we compared the results of two comparable problems of quotient, items #3 and #5. Item #3 asked preservice teachers to fold a 2-meter strip of paper into three equal pieces and identify the length of each piece, while item #5 asked for the amount of cake each child receives when sharing two cakes among three children. Item #3 can be modeled by using the linear model, whereas item #5 can be modeled by using the area model. The problem statement and correct percentage for each country can be seen in Table 8.

While the mean scores for both groups on item #5 were higher than those on item #3, only the difference produced by the U.S. preservice teachers was significant. The two-tailed p-value was less than .0001 at $\alpha =$ .05 when performing a paired t-test on the U.S. data. The same test on the Taiwan data produced a p value of .0832 at $\alpha = .05$. Furthermore, two groups responded very differently from each other on item #3. Among those who answered this item incorrectly,

Table 5
Scheffe post hoc *Test for Taiwan Data*

(I) Categories	(J) Categories	Mean Difference (I – J)	Std. Error	Sig.
Part–whole	Quotient	1.00741	3.29184	.993
	Equivalence	–3.69894	3.29184	.738
	Operations	22.18271(*)	3.29184	.000
Quotient	Part–whole	–1.00741	3.29184	.993
	Equivalence	–4.70635	3.29184	.564
	Operations	21.17529(*)	3.29184	.000
Equivalence	Part–whole	3.69894	3.29184	.738
	Quotient	4.70635	3.29184	.564
	Operations	25.88165(*)	3.29184	.000
Operations	Part–Whole	–22.18271(*)	3.29184	.000
	Quotient	–21.17529(*)	3.29184	.000
	Equivalence	–25.88165(*)	3.29184	.000

Note. * The mean difference is significant at the .05 level.

Table 6
Scheffe post hoc *Test for U.S. Data*

(I) Categories	(J) Categories	Mean Difference (I – J)	Std. Error	Sig.
Part–whole	Quotient	1.92562	4.15029	.975
	Equivalence	–18.29955(*)	4.15029	.000
	Operations	12.78798(*)	4.15029	.025
Quotient	Part–whole	–1.92562	4.15029	.975
	Equivalence	–20.22517(*)	4.15029	.000
	Operations	10.86236	4.15029	.079
Equivalence	Part–whole	18.29955(*)	4.15029	.000
	Quotient	20.22517(*)	4.15029	.000
	Operations	31.08753(*)	4.15029	.000
Operations	Part–whole	–12.78798(*)	4.15029	.025
	Quotient	–10.86236	4.15029	.079
	Equivalence	–31.08753(*)	4.15029	.000

Note. * The mean difference is significant at the .05 level.

Table 7
Correct Percentages with Respect to Each Type of Models

Model	United States (%)	Taiwan (%)
Area #1, #4, #5, #7, #11	79.1	90.8
Linear #3, #8, #9	44.6	89.4
Set #2, #6, #12, #10	54.8	85.9

40.8% preservice teachers from the U.S. chose $\frac{1}{3}$ meter and 22.8% chose .66 meter, while only 14.7% of the preservice teachers from Taiwan chose $\frac{1}{3}$ meter and 57.7% chose .66 meter. Thus, more U.S. preservice teachers agreed with $\frac{1}{3}$ meter than 0.66 meter as an answer, while their Taiwanese counterparts had an inverse agreement. The differences in the incorrect response patterns reflect different types of conceptual difficulty. An answer of $\frac{1}{3}$ meter would indicate that the teacher focused on only the "one" strip divided into "three" equal pieces, and failed to notice that the "quantity" for each piece needed to be measured with the standard unit, "meter." This is different from those answering .66, who had an oversight or error in precision.

Pictorial Illustration

In the last analysis, we compared the group performance with respect to the presence of a pictorial illustration. To examine the influence of the pictorial models, we compared preservice elementary teachers' performance on two pairs of items. All four items are based on the meaning of part–whole relationship, and one pair of items, #2 and #6, is based on set models, while the other pair of items, #8 and #9, is based on linear models. Table 9 includes the individual percentage of U.S. and Taiwanese preservice teachers that answered these items correctly. As shown in Table 9, the performance for both U.S. and Taiwanese preservice teachers reflects the same pattern: the success rate is higher on #2 (with pictorial illustration) than on #6 (without pictorial illustration), and higher on #9 (without pictorial illustration) than on #8 (with pictorial illustration). Furthermore, the paired *t*-test shows that the performance difference between #2 and #6 is not statistically significant ($\alpha = .05$) for both U.S. and Taiwanese preservice teachers, but the difference between #8 and #9 is significant ($\alpha = .05$) in both groups.

When examining the response patterns of both U.S. and Taiwan data, we found compatible results for #2 and #6, where the majority of the errors for both groups occurred when using all quantities referred to in the problem as the whole. However, all but one Taiwanese preservice teacher (out of 85) solved item #9 correctly, while only 64% of the U.S. preservice teachers solved this correctly. On item #8, close to 50% of the U.S. preservice teachers chose "None of the above," while only 4.7% of the Taiwanese preservice teachers chose that answer. We reviewed the test papers completed by the U.S. preservice teachers to search for clues of what other erroneous answers were given. Two answers stood out. One response was $\frac{3.5}{5}$, which is conceptually a correct answer but not in a form that is among the choices. Not recognizing that $\frac{3.5}{5}$ is equivalent to $\frac{7}{10}$, the correct answer, reflects an incomplete understanding of the symbol $\frac{3.5}{5}$. Another common incorrect answer was $\frac{1}{5}$, which was produced by counting backward by $\frac{1}{5}$ from $\frac{6}{5}$. This incorrect answer showed a lack of understanding of the number line structure. Therefore, the availability of a pictorial illustration may not be an aid to the thinking process if there is a conceptual obstacle in the understanding of the pictorial illustration itself, for example, the number line.

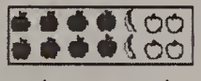
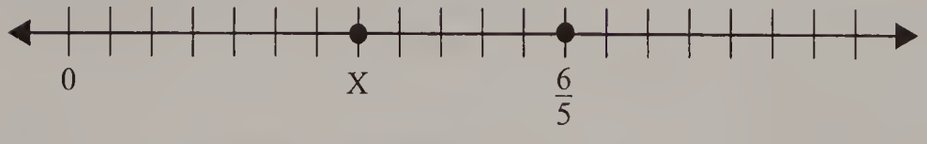
Discussion and Conclusions

Evidence from the research literature and this study makes it clear that elementary teacher education in the United States needs improvement. With the concern of cross-national differences in mathematics teacher quality, teacher education programs in the United States have been encouraged to enhance their mathematics courses offered to their preservice teachers and to provide more professional development opportunities to school teachers (Kulm, 2008). Further, the

Table 8
Items #3 and #5: Problem Statement and Correct Percentage for Each Group

Problem Statement	United States (%)	Taiwan (%)
3. A 2 ft. long strip of paper was folded into three equal pieces. How long was each piece? (a) $\frac{1}{3}$ ft. (b) $\frac{2}{3}$ ft. (c) $\frac{3}{2}$ ft. (d) 0.66 ft. (e) None of the above.	36.0	83.5
5. Aunt Rachel had 2 cupcakes for the kids to share equally. There were three kids. How much did each kid get? (a) 2 cupcakes (b) $\frac{3}{2}$ cupcakes (c) $\frac{2}{3}$ cupcake (d) $\frac{1}{3}$ cupcake (e) None of the above.	76.4	90.6

Table 9
Items #2, #6, #8 & #9: Problem Statement and Correct Percentage for Each Group

Problem Statement	United States (%)	Taiwan (%)
2. A basket contained 8 red apples, 2 bananas, and 4 green apples. What fraction of the apples is green?  (a) $\frac{4}{14}$ (b) $\frac{4}{12}$ (c) $\frac{8}{12}$ (d) $\frac{4}{8}$ (e) None of the above.	62.9	91.8
6. Brandon has a box which contains 7 red marbles, 3 purple buttons, and 5 green marbles. What fraction of the marbles is green? (a) $\frac{5}{15}$ (b) $\frac{5}{12}$ (c) $\frac{7}{12}$ (d) $\frac{5}{7}$ (e) None of the above.	53.9	83.5
8. What is the value of x?  (a) $\frac{7}{12}$ (b) $\frac{3}{5}$ (c) $\frac{7}{10}$ (d) $\frac{7}{15}$ (e) None of the above.	33.7	85.9
9. Jim jogged $1\frac{1}{2}$ miles yesterday. This is $\frac{3}{8}$ of his weekly goal. How many miles does he plan to run each week? (a) 3 miles (b) 4 miles (c) 5 miles (d) 6 miles (e) None of the above.	64.0	98.8

approach of having elementary school teachers as mathematics content specialists has been proposed (Li, 2008). In addition, in seeking an alternative more practical than increasing all elementary teachers' mathematical content knowledge, the National Mathematics Advisory Panel (2008) has suggested focusing the need for expertise on fewer teachers who are specialized in elementary mathematics teaching. Yet without taking into account what has led to the disappointing outcomes of mathematics teacher quality and examining factors that contribute to success in other countries, those suggested solutions may not achieve their effectiveness, as Ball's (2005) comments on the past efforts in the United States indicate. To provide better teacher preparation in mathematics, further research needs to be undertaken to examine the factors contributing to the outcomes and to provide improvements based upon them.

Moreover, because teacher education programs typically include more training in pedagogy methods than in content knowledge (Hill, Schilling, & Ball, 2004), it may be true that elementary teachers need to take more mathematics courses for teaching. However, based on this study, the number of mathematics courses taken by preservice teachers does not seem to be a primary factor that determines the observed difference. In this study, all the Taiwanese participants were non-science majors and were not required to take any college-level math courses for their programs. The only required mathematics education-related course is a mathematics method course, while U.S. preservice teachers have taken two or more required college-level mathematics courses or mathematics courses especially designed for future teachers. The result of the current study suggests an urgent need to examine the content and instruction of mathematics courses required for preservice teachers in the United States.

The overall result shows that the level of fundamental fraction knowledge possessed by the U.S. preservice teachers was much lower than that of their Taiwanese counterparts. However, with a few exceptions, preservice teachers from the United States and Taiwan responded similarly to this assessment in terms of what appeared to be challenging and what appeared to be easy for them. Both groups had a solid understanding on the importance of having the same whole when comparing two fraction quantities and were able to choose the correct story that modeled fraction subtraction. Both groups of preservice teachers encountered difficulty in choosing the appropriate representation for a given multiplication sentence. In mathematics learning and teaching, the transitions from a concrete (hands-on), pictorial, or verbal representation to symbolic representation such as a number sentence are often addressed, but the discussion on inverse transitions from a symbolic representation to visual or verbal representation is limited. The ability to analyze and understand the mathematical meanings embedded in the conventional representations such as number line or the student-generated representations, as well as the knowledge of the affordance and limitations of different representations, is important mathematical knowledge needed for teaching (Ball et al., 2008; Izsák, 2008; Shulman, 1986). Izsák found that the middle school teachers in his study tended to use just pictorial representations for illustration rather than as a tool to help with reasoning and making connections. The crucial difficulty in making such inverse transitions in fraction multiplication and division remains to be understood. Further studies must be undertaken to explore ways to enhance the flexibility and capability of preservice elementary teachers in representing the meanings of non-whole number multiplication and division.

Furthermore, this study found that U.S. preservice teachers had more difficulty with problems with a linear model, especially working with the number line. As the National Mathematics Advisory Panel (2008) states:

> As with learning whole numbers, a conceptual understanding of fractions and decimals and the operational procedures for using them are mutually reinforcing. One key mechanism linking conceptual and procedural knowledge is the ability to represent fractions on a number line. The curriculum should afford sufficient time on task to ensure acquisition of conceptual and procedural knowledge of fractions and of proportional reasoning. Instruction focusing on conceptual knowledge of fractions is likely to have the broadest and largest impact on problem-solving performance when it is directed toward the accurate solution of specific problems. (p. xix)

The teacher education programs in the United States need to provide opportunities for their preservice elementary teachers to develop fluency with fractions on a number line.

Although this study involved only a small-scale comparison between preservice elementary teachers in the United States and Taiwan, the range of their knowledge of fractions performance matches the wide gap of student mathematics achievement found in two recent large-scale international studies—TIMSS 2007 and PISA 2006 (Mullis et al., 2008; OPED, 2007). To ensure that school students in the United States have the opportunity to learn comparable mathematics knowledge as school students in Taiwan, research efforts need to be undertaken to investigate other potential factors affecting this international gap and to address how to raise U.S. preservice teachers' mathematics knowledge.

The design of our study did not allow us to conduct a rigorous analysis regarding the factor interactions. It is unclear what the results would be when two or more factors are considered at the same time. Recall that all the pictorial items without significant difference in performance between the U.S. and Taiwanese groups were also embedded in an area model. Future study with more complex test design is needed to sort out the interactions among multiple factors. Another potential limitation of this study was the classification of the test items. Our classifications of models were based on the problem contexts. However, we acknowledge that preservice teachers might use a different model than the one suggested by the problem statements. Without adopting a qualitative approach such as interviews for understanding how participants processed the given items, the patterns and insights generated from this study are limited. To gain deeper and more sufficient information, a rigorous more and thorough study must be undertaken in the future.

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Gender-Related Beliefs and Mathematics Performance of Preservice Primary Teachers

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The aim of this study was to examine whether there are gender differences in mathematics achievement and in beliefs about mathematics of preservice teachers over a period of four years. Data were collected from preservice teachers (156 males and 155 females) from the Adıyaman University Faculty of Education in Turkey. The Mathematics as a Gendered Domain instrument was used to investigate preservice teachers' beliefs about the gender differences in mathematics. The results indicated that gender had no effect on mathematics performances of the preservice primary teachers. Findings of this research show that most of the male and female preservice primary teachers do not gender-stereotype mathematics and believe that mathematics is gender neutral, although there are gender differences on some types of items of instrument.

The paper attempts to determine whether there are significant gender differences in mathematic performance and belief about mathematics in a sample of preservice teacher with ages between 18–25 years, in Adıyaman University. Most of the research on gender difference in mathematics achievement and beliefs about mathematics has been conducted in North America and Europe or others part of world (e.g., Fennema & Sherman, 1978; Hyde, Fennema, & Lamon, 1990; Ma, 1995). Turkey is a very important country in terms of geopolitical location. Turkey is a bridge between West and East, Europe and Asia, Islamic culture and Christian culture, and influenced greatly by both East and West. For this reason, Pope and Pope (2004) stated that Turkey has been constantly described as "European, Western, Eastern, Islamic."

In Turkey, civil and family laws were introduced in 1926 to establish gender equity. The modernized civil and family laws have allowed equal rights to women and men in education, employment, and inheritance, and further equalized women's and men's rights and obligations in case of divorce (Ongen, 2007). However, gender prejudice and the second-class status of women in the Middle East is still very prevalent in rural regions, particularly in east and southeast Anatolia, because the region's culture is conservative and general family pattern is predominantly patriarchal (Dayıoğlu & Türüt-Aşık, 2007; Gülerce, 1995; Pinar, Eser, & Hardin, 2007; Sakallı 2001).

Levels of education, particularly for girls, are lower in the less developed east and southeast Anatolia regions than other parts of Turkey (Sahin & Gülmez, 2000; Tansel, 2002). The rate of illiteracy in southeast Anatolia is 39.8%, and 34.1% in east Anatolia; 75% of these are women (Prime Ministry General Directorate on The Status of Women [PMGDSW], 2008). Similarly, in terms of socio-economic development order, while the rate of literate women population to the total women population is 86% in the first group that includes cities in the west of Turkey, this rate is 53% in the 6th group that includes rural areas and cities in East Anatolia Region (Prime Ministry State Planning Organization [PMSPO], 2004).

In these regions, education has been stereotyped as a male domain (Tan, 1979), and there is important evidence to support this view. Parents do not send girls to school (PMGDSW, 2008; UNESCO, 2003; Yasar, 2007), and more than half of the married women in the towns and countryside of east and southeast Turkey had not completed primary education and were not able to read easily (Hosgör & Smits, 2006). In rural regions, parents generally tended to stereotype education as male domain and the dominant opinion is that "What will happen when girls attend to school?" (Tan). PMGDSW reported that low-income families, who want to educate at least one of their children, prefer boys to be educated and keep their girls at home. In southeast and east Anatolia, "Existing gender roles stimulate a traditional culture and form one of the most important hindrances for the schooling of girl children. Patriarchal family structures and traditional ways of thinking make parents keep their daughters at home and not send them to school" (PMGDSW, p.25). Therefore, it may show the number of girls who were not sent to schools by their parents in the regions mentioned is in the hundreds of thousands. In addition, PMGDSW also reported that those socioeconomic situations are leading elements that affect the education level. Similarly, most of the studies have shown that family's socioeconomic status

and parental education promotes the education of children (Buchmann, 2000; Lloyd & Blanc, 1996; Tansel, 2002). Therefore, some families either prevent their girls to go to school on time or they do not send the girls to the school at all by making these girls work in agricultural works or do housework such as dish washing, cooking and washing clothes (Bruce & Isik, 2006; PMGDSW, 2008). For this reason, The United Nations Children's Fund [UNICEF] and Turkish Ministry of Education [TME] (1992) developed projects for improving girls' access to schooling. Furthermore, civil society organizations developed a variety of projects in order to increase girls' enrollment in schools. Government provides financial supports to the families in order for them to be able to send their girls to schools, and gives some penalties or fines to the families who do not. Moreover, in Turkey, certain vocations and professions related to mathematics have traditionally been regarded as men's (mathematics, medicine, engineering, architecture), and others as women's (nursing, social science, literature, arts) (Savaş & Duru, 2005; Tan, 1994).

In Turkey, where two different cultures meet, an examination of the role of gender on preservice primary teachers' mathematics achievement and beliefs about mathematics is important. Thus, the present study investigated whether there was any gender difference on preservice primary teachers' mathematics performances and their beliefs about mathematics.

Review of the Literature

For the last four decades, mathematics educators have focused on gender difference in mathematics performance (Alkhateeb, 2001; Ercikan, McCreith, & Lapointe, 2005; Fennema, 1974; Hyde, 2005; Isiksal & Cakiroglu, 2008; Leder, 1985; Penner & Paret, 2008; Randhawa, 1994; Savaş & Duru, 2005). Some findings have shown that gender differences in mathematics performance do not exist in elementary or secondary school, but exist in high school and college (Leahey & Guo, 2001; Leder, 1985; Muller, 1998; Peterson & Fennema, 1985). Muller (1998) and Leahey and Guo (2001) found that although there were no gender differences among middle school students, differences emerge as students progress through high school. However, recent research (Penner & Paret, 2008; Rathbun, West, & Germino-Hausken, 2004) show some evidence that gender differences might emerge at earlier ages. Penner and Paret explored gender differences in mathematics achievement in early grades. They use data from the Early Childhood Longitudinal Study, Kindergarten Class of 1998–1999 to analyze differences in a nationally representative sample of kindergartners as they progress from kindergarten to fifth grade. Penner and Paret indicated that gender differences in mathematics achievement emerge as early as first grade.

Findings regarding gender differences in mathematics achievement are not clear. Many studies (Hedges & Nowell, 1995; Peterson & Fennema, 1985; Randhawa, 1994; Wilson & Hart, 2001) found that boys in high school generally had higher scores than girls in mathematics. For example, Randhawa (1994), Wilson and Hart stated that boys tend to outperform girls during the high school years. Other studies (Barker, 1997; Hyde, Fennema, & Lamon, 1990) showed that this gap had declined. In addition, some recent studies (Alkhateeb, 2001; Bornholt, Goodnow, & Cooney, 1994; Ma, 1995; Savaş & Duru, 2005) have shown no gender differences in mathematics achievement. Cheng and Seng (2001) compared gender differences in seventh and eighth graders student' mathematics achievement in TIMSS of four Asian nations, Singapore, Japan, Korea, and Hong Kong. Cheng and Seng found statically significant gender differences in Hong Kong and Korea, to a lesser degree in Japan, and least in Singapore. Considering the results of their studies, it has been seen that Singaporean girls' achievements tend to be better than boys', but in Japan, Korea, and Hong Kong, males still have advantages in mathematical achievement in the seventh and eighth grades. Alkhateeb (2001) explored gender differences in student' mathematics achievement in last grade of high school in the United Arab Emirates. Alkhateeb selected a random sample of 2,000 students—100 male and 100 females for each academic year—from the Ministry of Education records, and achievement results for males and females were compared, and no significant overall differences were found between girls' and boys' mathematics achievement in high school. Ma (1995) researched the gender-related issues in four education systems (British Colombia, Ontario, Hong Kong, and Japan) and reported no gender differences in algebra, but eighth grade male students showed remarkably higher performance in geometry than female students did. In addition, Ma claimed that gender differences in algebra and geometry might not be dependent on the education system in which students attend. He argued

that although education policies and practices were different from system to system, mathematics teachers in four different systems might face similar situations in terms of gender differences in algebra and geometry.

Arigbabu and Mji (2004) investigated gender differences in mathematics performance among Nigerian preservice teachers. They analyzed the final year results of 374 preservice mathematics teachers (170 males and 202 females) who graduated from a college of education in the southwestern part of Nigeria between 1999 and 2001. Arigbabu and Mji reported that the gender difference in mathematics achievement among the sample data could be disappearing. Even some studies such as Damarin (1995) reported that girls' performance tends to be better than boys' on tasks/problems with well-defined procedures.

A few studies were conducted on gender differences in mathematics performance and beliefs about mathematics in Turkey (Isiksal & Askar, 2007; Isiksal & Cakiroglu, 2008; Savaş & Duru, 2005; Ubuz, 1999). Savaş and Duru explored the role of gender on mathematics achievements and attitudes toward mathematics among first grade high school students in the city center of Van province. Savaş and Duru have found no significant difference between the mean scores of boys and girls in the mathematics test. In addition, Savaş and Duru also found that there was no significant difference between the mean scores of boys and girls on the attitude toward mathematics. lsiksal and Askar investigated the effects of dynamic geometry software on mathematics achievements of seventh grade Turkish students. Isiksal and Askar found no gender differences between boys and girls with respect to mathematics achievement. Isiksal and Cakiroglu explored gender differences in mathematics achievement using the mathematics subsection of a nationwide high school entrance examination in Turkey. They separated the cities of Turkey into five groups in terms of their level of socioeconomic development, and randomly selected 2,647 students (1,297 female and 1,350 male) from these five different groups. The results of their study showed that there was a statistically significant gender difference in favor of boys in the first, second, and third groups of cities, with very small effect sizes for each comparison. In addition, they have found no statistically significant gender difference between boys and girls in the fourth and fifth groups of cities. In another study, Ubuz (1999) investigated students' understanding of angle concept in geometry according to students' errors, misconceptions, and gender. Ubuz's sample of research consists of one 10th grade class and one 11th grade class selected from a private college in Ankara in the 1997–1998 academic year. She reported that either most of male students gave a correct response to the questions or they did not respond to the question. In addition, Ubuz reported that female students were more successful when compared to male students, and there was an increase in the achievement level of the students due to educational level. In addition, findings presented in the TIMSS (Mullis et al., 1999) showed that the performances of eighth grade Turkish male and female students on the mathematics test were not statistically significantly different (Mullis, Martin, Fierros, Goldberg, & Stemler, 2000).

The other issue is related to beliefs in the studies of mathematics and gender. Earlier research (Boswell, 1985; Fennema & Sherman, 1977, 1978; Stage & Kloosterman, 1995) showed that there is a relationship between mathematical achievement and beliefs about mathematics. Fennema and Sherman, using the Fennema–Sherman Mathematics Attitudes Scale, have found that males also had higher scores on attitude scales, including Confidence in Learning Mathematics, viewing Mathematics as a Male Domain, Attitude Toward Success in Mathematics, Mother's Support, Father's Support and Usefulness of Mathematics. Later studies investigating gender differences in attitudes toward mathematics reported similar results (Duffy, Gunther, & Walters, 1997; Forgasz & Leder, 1996; Kloosterman, 1988). Although earlier studies reported mathematics as a male domain, Forgasz and Leder (2000) stated that stereotyping within mathematics is decreasing. In other studies, Kloosterman, Tassell, Ponniah, and Essex (2001) investigated students' perceptions about gender and mathematics in the United States. Kloosterman et al. reported that students believed mathematics as gender neutral. Nevertheless, females hold this belief more strongly than males, and they found statistically significant gender differences in the approach students view certain types of mathematics learning experiences, and there are differences by site and level on some types of items.

In recent years, increasing attention has been paid by mathematics researchers to different aspects of teacher and preservice teacher beliefs about mathematics, such as beliefs about the nature of mathematics (Ernest, 1988; Grossman, Wilson, & Shulman, 1989), beliefs about teaching and learning of

mathematics (Ball, 1990; Cobb, Wood, & Yackel, 1990; Handal, 2001; Prawat, 1990), and beliefs about the mathematics curriculum (Brew, Rowley, & Leder, 1996; Foss & Kleinsasser, 1996; Gooya, 2007; Grant, Hiebert, & Wearne, 1994) and beliefs about student gender differences (Fennema, Peterson, Carpenter, & Lubinski, 1990; Fennema, Ryan, Frost, & Hopp, 1990) and possible relationships between those beliefs and the practice of teaching (Kagan, 1992; Pajares, 1992; Thompson, 1992).

Teachers exhibit gender bias in the mathematics classes. Research has shown that teachers, consciously or unconsciously, behave differently to boys and girls in their classrooms (Jussim & Eccles, 1992; Rubble & Martin, 1998). Li's (1999) meta-review of studies on the influence of teachers' beliefs on gender differences in mathematics achievement showed that teachers had different expectations of girls and boys. Generally, teachers have higher expectations from male students than female students (Hilton & Berglund, 1974), and they think that male students are better than female students at mathematics (Casserly, 1975). Teachers believed that boys were more talented at mathematics than girls were, even though there was no gender difference in standardized test scores. Teachers believed that girls tried harder than boys did although there were no gender differences in self-perception of effort or time spent on homework (Jussim & Eccles). Literature has shown that teachers' beliefs have significant influences on students' achievement in mathematics. Preservice primary teachers are considered as future educational leaders (Arigbabu & Mji, 2004). Therefore, it is important to understand whether there are gender differences between mathematics performances and beliefs of preservice primary teachers. In other parts of the world, although few studies have been done on gender differences in mathematics performance among preservice teachers and their beliefs about mathematics, no study has been done on this subject in Turkey. For that reason, the result of this study will provide important information to the literature related to gender and mathematics. The present study was designed to explore gender differences in mathematics performance and attitudes toward and beliefs about mathematics held by preservice primary teachers, most of whom are from east and southeast Anatolia in Turkey

The present study investigated whether there were any gender difference on preservice primary teachers' mathematics performances and their beliefs about mathematics. The research questions that guided the study were as follows:

1. Is there a gender difference between preservice primary teachers about mathematics achievement scores?
2. Is there a gender difference between beliefs of preservice primary teachers about mathematics?

Method

Participants

Participants were 156 males (50.2%) and 172 females (49.8%), aged 18–25 years, who attended the Department of Primary Education in the Faculty of Education at Adıyaman University in southeast Anatolia between 2004 and 2008, most of whom coming from east and southeast Anatolia themselves. Final semester academic achievement scores of preservice primary teachers at the end of their four-year program were collected as data in this study.

Instruments

A total of 311 preservice primary teachers' grades obtained from Basic Mathematics I and II courses at the end of the semester were used in order to investigate gender differences on their mathematics performance. The preservice teachers take the Basic Mathematics I course, which mainly consists of sets and operations with sets, setting number system, natural numbers, different base numbers, Cartesian operations, functions, operations, and graphs. Data collection, summary of the data, data graphs, (mean, peak value, median) distributions (range and deviations), and the Basic Mathematics II course, which mainly consists of equations and identity concepts, equalities and inequalities, system of equations and inequalities construction of geometry, plane shapes, perimeters and areas, three dimensional objects, areas and volumes, similarity rules, perpendicular triangles, Pythagoras rule, metric relations in perpendicular triangles, basic geometrical drawings, basic concepts of trigonometry, and analytics of lines and circles. This content was in line with the curriculum approved for all Faculties of education in Turkey by the regulatory body; the Higher Education Council. Basic Mathematics I and II are compulsory courses for students. Before 2006, at each semester, students took two mid-semester examinations and one final examination. Conditional evaluation was applied. The total mark is 100, and 50% of it comes from the final examination and 25% from each of the two mid-semester examinations. After application of the conditional evaluation

each student is assigned one of AA (4.0), BA (3.5), BB (3.0), CB (2.5), CC (2.0), DC (1.5); DD (1.0), FD (0.5), FF (0.0) grades by the course instructor. Students must obtain at least DD from each course and have a cumulative grade point average of not less than 2.00 out of 4.00.

After 2006, at each semester, students started to take one mid-semester examination and one final examination, and absolute evaluation was applied. The total mark is 100—60% from the final examination and 40% from the mid-semester examination. Students must obtain at least 60 out of 100 from each course. Collected data were used to establish whether there was a gender difference in mathematics performance.

The Mathematics as a Gendered Domain instrument was used to investigate gender related beliefs (Leder & Forgasz, 2002). The three subscales are Mathematics as a Male Domain [MD], Mathematics as a Female [FD], and Mathematics as a Neutral Domain [ND]. Sample items from each scale include:

MD: Boys understand mathematics better than girls do.

FD: Girls are more suited than boys to a career in a mathematically related area.

ND: Boys are just as likely as girls to help friends with their mathematics.

The Mathematics as a Gendered Domain instrument was translated into Turkish. Two mathematics educators, one education researcher, and one instructor at the Department of Foreign Languages at Adıyaman University oversaw and edited the original forms and the Turkish translation of the Mathematics as a Gendered Domain items used in the present study. There was no need to back translation to Turkish according to the views of experts. These procedures were done to provide issues of construct and content validity (Mcmillan & Schumacher, 2001). Because it was developed in the English context, the suitability, validity, and reliability of the instrument for administration in a Turkish context had to be established. In a process similar to that used by Leder and Forgasz (2002), a confirmatory factor analysis was conducted to check whether the mathematics as a gendered scale consisted of three different subscales. The results of Varimax rotation of the present study were similar to the results of factor analysis by Forgasz, Leder, and Kloosterman (2004) and Leder and Forgasz. Three factors comprising the items on each of the three subscales were categorized. The 16 items forming each subscale were loaded on separate factors.

In addition, a reliability analysis was conducted on the items comprising each subscale. For each subscale, item-total correlations confirmed the internal consistency of the items. For mathematics as a male domain, the Cronbach's alpha was .91, Cronbach's alpha was .83 for the mathematics as a female domain subscale, and .75 for the mathematics as a gender-neutral domain subscale. These values are similar to the Cronbach's alpha values of $\alpha_{MD} = .902$, $\alpha_{FD} = .897$, and $\alpha_{ND} = .836$ reported by Leder and Forgasz for Mathematics as a Gendered Domain.

Procedure

Participation was voluntary, with consent obtained from participants. A total of 311 preservice primary teachers completed this instrument, which was administered by the researcher. Most students completed the survey in less than 10 minutes.

Data Analysis

The data were analyzed using SPSS version 15. Students' mathematics performances and beliefs toward mathematics were used as dependent variables. The independent samples *t*-test procedure was used to compare means for males and females. Value ranges (Tekin, 1996) are as follows: "Range 1($\bar{x} = 1.00–1.79$) is not strongly ND or MD or FD; Range 2 ($\bar{x} = 1.80–2.59$) is not ND or MD or FD; Range 3 ($\bar{x} = 2.60–3.39$) is neutral; Range 4 ($\bar{x} = 3.40–4.19$) is ND or MD or FD; Range 5 ($\bar{x} = 4.20–5.00$) is strongly ND or MD or FD" for subscales of MD, FD, and ND. Statistical correction, Bonferroni and Šidàk correction for multiple comparisons, was done since many individual t-tests were employed to compare means for males and females, one for each item (Abdi, 2007). Minimum acceptable level of significance was set at .01 for three and 4 items and .001 for 16 items.

Results

The first research question focused on role of gender in mathematics performance of preservice primary teachers. Tables 1 and 2 show mean scores obtained from both males and females, together with the *t*-values for each semester of investigation. It can be seen in Tables 1 and 2 that for academic years 2004–2005 and 2005–2006, as well as the first semester of 2006–2007, girls had higher scores than boys. As for the second semester of 2006–2007 and the 2007–2008 academic year, boys had higher mean scores than girls. For each semester, the obtained *t*-values were less than the critical value of 1.9. Thus,

Table 1
Mathematics I Mean Scores, SDs, and t-Values for Academic Years

Years	Males		Females		t_1
	$\bar{x}_{M_1}$	*SD*	$\bar{x}_{M_1}$	*SD*	
2004–2005	1.75	.64	1.82	.50	.45
2005–2006	1.78	.56	1.85	.62	.55
2006–2007	64.52	15.20	67.16	5.97	1.11
2007–2008	68.50	6.25	67.80	7.94	0.37

Table 2
Mathematics II Mean Scores, SDs, and t-Values for Academic Years

Years	Males		Females		t_2
	$\bar{x}_{M_2}$	*SD*	$\bar{x}_{M_2}$	*SD*	
2004–2005	1.41	.61	1.50	.81	.48
2005–2006	1.39	.47	1.50	.63	.90
2006–2007	64.40	15.59	63.79	10.3	.22
2007–2008	67.32	9.94	64.25	9.13	1.26

there was no significant differences between boys' and girls' mathematics performance. This implies that gender did not influence preservice primary teachers' mathematics performance.

The second research question focused on the relationships between the beliefs of the preservice primary teachers and their gender. For each of the three subscales, the mean score was calculated and *t*-tests for gender differences were applied.

The results for the responses given by female and male students were also compared. As can be seen in Table 3, the means by gender on the neutral domain scale were 3.77 for males and 3.96 for females. For neutral domain scale, the *t*-calculated value of 3.43 was greater than the *t*-critical value of 2.58. On the male domain scale, means were 2.91 for males and 2.27 for females. For the male domain scale, the *t*-calculated value of 7.24 was greater than the *t*-critical value of 2.58. Finally, on the female domain scale, means were 2.39 for males and 2.65 for females. For female domain scale, the *t*-calculated value of 3.68 was greater than the *t*-critical value of 2.58. In other

Table 3
Gender Differences in Mathematics as a Gendered Domain

Subscale	Males		Females		*t*
	$\bar{x}$	*SD*	$\bar{x}$	*SD*	
ND	3.77	.48	3.96	.46	3.43*
MD	2.91	.75	2.27	.73	7.24*
FD	2.39	.51	2.65	.67	3.68*

Note. The score for each subscale ranges from 1 to 5, with 1 indicating strong disagreement and 5 indicating strong agreement. Levels of statistical significance for *t*: * $p < .001$.

words, while both groups ($3.40 < \bar{x}_M = 3.77 < 4.19$ and $3.40 < \bar{x}_F = 3.96 < 4.19$ believed that mathematics is a gender-neutral domain and that it is neither a male nor a female domain, females students were stronger in their beliefs than were male students. The males were unsure if mathematics was a male domain ($2.60 < \bar{x}_M = 2.91 < 3.39$), whereas the females disagreed that it was ($1.80 < \bar{x}_F = 2.27 < 2.59$), and the both groups disagreed that mathematics was a female domain ($1.80 < \bar{x}_M = 2.39 < 2.59$ and $\bar{x}_F = 2.65$ scores approx. 2.59 upper limit of range 2).

For exploring gender differences, given responses to items in each of the subscales were analyzed. As can be seen in Table 4, males and females both generally agreed that mathematics was a neutral domain (most of mean scores > 3.40). Nevertheless, there were statistically significant gender differences on 15 of the 16 items on the mathematics as a gender-neutral domain subscale, with females agreeing more strongly than males on 12 of the 16 items.

As can be seen in Table 4, the largest differences between males and females were observed in the following three questions:

1. Women and men are equally likely to be good mathematics teachers (Ability).
2. Students who get poor marks on mathematics test are just as likely to be boys as girls (Task).
4. Being good at mathematics comes as naturally to girls as to boys (Ability).

Table 5 shows the difference by item on the mathematics as a male domain subscale. As can be seen

Table 4
Gender Differences in Mathematics as a Gender Neutral Domain by Item

Items	Males		Females		*t*
	$\bar{x}$	*SD*	$\bar{x}$	*SD*	
1. Women and men are equally likely to be good mathematics teachers.	3.94	1.20	4.45	.95	4.07*
2. Students who get poor marks on mathematics test are just as likely to be bays as girls.	4.20	.91	4.62	.75	4.07*
3. Parents think that getting high grades in mathematics is as important for their daughters as for their sons.	4.04	.99	4.39	.90	3.28
4. Being good at mathematics comes as naturally to girls as to boys.	4.07	1.07	4.74	.65	6.7*
8. It is just as difficult for girls as it is for boys to get a job in a mathematically related profession.	3.36	1.18	3.47	1.31	.73
9. Boys are just as likely as girls to enjoy mathematics.	3.89	1.04	4.05	.94	1.38
11. Girls and boys who do well in a mathematics test are just as likely to be congratulated.	4.38	.98	4.69	.79	3.07
15. Girls and boys are just as likely to be lazy in mathematics classes.	2.79	1.14	2.78	1.38	.035
19. Parents are as likely to help their daughters as their sons with mathematics.	4.30	.89	4.55	.85	2.53
25. Students who say mathematics is their favourite subject are equally likely to be girls or boys.	3.33	1.19	3.59	1.21	1.90
30. Men and women are equally suited to careers in the computer industry.	3.46	1.12	3.76	1.22	2.22
31. Girls and boys are equally likely to believe that mathematics is important for their career.	3.67	1.14	3.88	1.20	1.52
38. Girls are just as likely to work hard in mathematics as boys.	3.86	1.10	3.42	1.36	3.16
42. Boys are just as likely as girls to help friends with their mathematics.	3.88	.99	3.85	1.06	.27
45. Boys and girls are equally good at using calculators in mathematics.	3.08	1.08	3.53	1.17	3.46*
47. Girls are just as likely as boys to say they want to excel in mathematics.	3.91	.93	3.87	1.19	.32

Note. The score for each subscale ranges from 1 to 5, with 1 indicating strong disagreement and 5 indicating strong agreement. Levels of statistical significance for *t*: * $p < .001$.

from the table, the males were unsure if mathematics was a male (2.60 < most of items' mean scores < 3.39), whereas the females disagreed (1.80 < most of items' mean scores < 2.59). Nevertheless, there were statistically significant gender differences on 15 of the 16 items with females disagreeing more strongly than males on every item. The largest differences between males and females were observed in the following three questions:

12. Boys have more use for mathematics than girls do when they leave school. (Career-related)

22. More boys than girls care about doing well at mathematics. (General Attitude)

33. Men are mathematically more intelligent than women. (Ability)

For the mathematics as a female domain subscale, item-by-item gender differences can be seen in Table 6, which shows that males and females both generally disagreed that mathematics was a female domain (generally, 1.80 < items' mean scores < 2.59). Nevertheless, female students generally were stronger in their beliefs than were male students. There were

Table 5
Gender Differences in Mathematics as a Male Domain by Item

Items	Males		Females		*t*
	$\bar{x}$	*SD*	$\bar{x}$	*SD*	
5. Mathematics is easier for men than it is for women.	2.82	1.35	2.17	1.30	4.24*
10. Boys are more determined than girls to do well in mathematics.	3.12	1.27	2.31	1.25	5.62*
12. Boys have more use for mathematics than girls do when they leave school.	3.56	1.24	2.64	1.29	6.39*
20. Boys, more than girls, want to do well in mathematics to please their parents.	2.92	1.18	2.39	1.16	3.95*
21. Compared to boys, girls do less work in mathematics classes.	2.57	1.16	2.24	1.14	2.51
22. More boys than girls care about doing well at mathematics.	3.08	1.20	2.27	1.21	5.88*
23. Mathematics is liked more by boys than by girls.	2.94	1.27	2.34	1.24	4.19*
26. It is more acceptable for a man than a woman to be good at mathematics.	3.39	1.37	2.58	1.32	5.29*
27. Career choices make the study of mathematics more important for boys than for girls.	3.31	1.31	2.56	1.28	5.05*
29. Boys, more than girls, like challenging mathematics problems.	3.68	1.20	3.03	1.32	4.53*
33. Men are mathematically more intelligent than women.	3.18	1.34	2.29	1.22	6.04*
34. Boys are encouraged more than girls to do well in mathematics.	2.66	1.26	2.16	1.14	3.62*
37. There are more popular boys than popular girls who are good at mathematics.	3.74	1.14	3.13	1.41	4.22*
46. The mathematical tasks done in class suit boys more than they suit girls.	2.77	1.15	2.10	1.05	5.30*
48. Girls are less interested in mathematics than are boys.	3.01	1.23	2.37	1.28	4.47*

Note. The score for each subscale ranges from 1 to 5, with 1 indicating strong disagreement and 5 indicating strong agreement. Levels of statistical significance for *t*: * $p < .001$.

statistically significant gender differences on 6 of the 16 items on the mathematics as a female domain subscale. The three items that had the largest gender differences were given as:

7. Girls have more natural mathematical ability than do boys. (Ability)

39. Girls are more careful than boys when doing mathematics. (Effort)

41. Girls care more about doing well at mathematics than boys do. (General Attitude)

Conclusion and Discussion

In this study, gender differences in the mathematics performance of preservice teachers were investigated over a four-year period. The results revealed that preservice primary teachers' mathematics performances were not influenced by gender. The results further show that in the first two years and in the first semester of the third year, female students performed slightly higher than male students. In the remaining year and a half, the differences were not statistically significant.

Many studies have been conducted regarding gender differences in mathematics but findings regarding gender differences in mathematics achievement are not clear. The findings of this study agrees with findings of previous research (Isiksal & Askar, 2007; Savaş & Duru, 2005) regarding gender differences in mathematics achievement that were conducted in Turkey and other countries (Alkhateeb, 2001; Bronholt et al., 1994; Ma, 1995). Savaş and Duru showed that there was no significant difference in the mean achievement scores of boys and girls in

Table 6
Gender Differences in Mathematics as a Female by Item

Items	Males		Females		*t*
	$\bar{x}$	*SD*	$\bar{x}$	*SD*	
6. Girls are more suited than boys to a career in a mathematically related area.	2.04	.98	2.52	1.18	3.85*
7. Girls have more natural mathematical ability than do boys.	1.86	.96	2.51	1.15	5.33*
13. Parents believe mathematics is more important for their daughters than for their sons.	2.37	1.10	2.33	1.20	.31
14. Explaining answers in mathematics is harder for boys than for girls.	2.24	1.10	2.31	1.25	.47
17. Girls enjoy mathematics more than boys do.	2.16	.92	2.39	1.11	1.97
18. Boys are distracted from their work in mathematics classes more than are girls.	2.56	1.07	2.70	1.19	1.08
24. The weakest mathematics students are more often boys than girls.	2.04	.87	2.48	1.06	3.99*
28. Compared to girls, boys give up more easily when they have difficulty with a mathematics problem.	2.15	1.12	2.69	1.21	4.00*
32. In a mathematics class with both boys and girls, girls tend to speak up more than boys.	2.46	1.08	2.71	1.21	1.93
35. Boys, more than girls, say the mathematics test was too hard if they do not do well.	2.84	1.22	2.95	1.26	.82
36. Girls are encouraged more than boys to do well in mathematics.	2.81	1.23	2.54	1.25	1.91
39. Girls are more careful than boys when doing mathematics.	2.61	1.07	3.22	1.23	4.62*
40. When they leave school, girls will have more use for mathematics than boys will.	2.16	1.06	2.43	1.01	2.26
41. Girls, more than boys, care about doing well at mathematics.	2.47	1.15	3.07	1.25	4.35*
43. Girls are more likely than boys to believe they are good at mathematics.	2.70	1.18	2.67	1.02	.23
44. Girls are more likely than boys to say mathematics is their favorite subject.	2.55	1.08	2.69	1.18	1.13

Note. The score for each subscale ranges from 1 to 5 with 1 indicating strong disagreement and 5 indicating strong agreement. Levels of statistical significance for t: * $p < .001$.

mathematics. Similarly, Isiksal and Askar revealed that gender had no effect on students' achievement mean scores. In addition, findings presented in the TIMSS (Mullis, et al., 1999) were in consonance with findings of the present study. Mullis et al. (2000) reported that there were no statistically significant differences in the performances of eighth grade Turkish male and female students in mathematics. However, the results disagreed with Peterson and Fennema (1985), Randhawa (1994), Hedges and Nowell, (1995), and Wilson and Hart (2001), who found that there were significant differences in the mathematics achievement of male and female students.

Also in this study, gender differences in the beliefs about mathematics of preservice teachers were investigated. For each of the three subscales—ND, MD, and FM—statistical tests were conducted to compare the responses of boys and girls. In general, preservice teachers strongly agreed that mathematics was a gender-neutral domain. However, males were less

convinced of this than were females. The males were unsure if mathematics was a male domain whereas the females disagreed, and the both groups disagreed that mathematics was a female domain. In other words, the findings of this research indicate that most male and female students do not see mathematics as gender-stereotyped and believe that mathematics is gender neutral. These findings agree with Forgasz, Leder, and Kaur (1999), as well as Forgasz et al. (2004), who reported that in general students strongly agreed that mathematics was a gender-neutral domain.

There are two important outcomes of this study for Turkey. First, it was found that gender had no effect on mathematics performance of students. Second, students in Turkey generally believe much more strongly that mathematics is a neutral domain than either a male or a female domain. These findings are important since most of participants in this study are from either east and southeast Anatolia or rural regions, where many people believe that getting education is a man's job (PMGDSW, 2008; Tan, 1979). In these regions, hundreds of thousands of girls are not sent to schools, socioeconomic situation is worse than the other regions of Turkey, and level of education is much lower (PMGDSW, 2008).

Although hundreds of thousands of girls are not sent to schools, it could be noted that recent studies have noted fewer gender differences. As mentioned in the introduction, in the last 15–20 years, there have been improvements in both education levels of families and their socioeconomic status. This has led to changes in families' views of their children's education. Isiksal and Cakiroglu (2008) found that there is relatively equal performance in mathematics in both sexes. However, they said that there might still be striking socioeconomic differences among families, which could be a critical factor in students' achievement. As a result of studies carried out, families whose socioeconomic conditions are improving and whose socioeconomic conditions are not well enough have started to send their daughters to schools thanks to support from the government. This could be a factor that affect research findings.

Religion and moral values is a factor to be considered. Many people in south Anatolia do not send their daughters to schools because they believe that it is a sin to send girls to school. With the increase in education level of families, these types of beliefs have started to disappear and, conversely, it has been understood by many that religion encourages education. There are verses in Muslim holy books and traditional adages encouraging people to seek education. These encouraging words give advice parents to educate both males and females. Therefore, families whose education level increased have begun to send their daughters to school and believe that girls could be successful in lessons such as mathematics. This has led to girls succeeding in mathematics and developing positive attitudes toward mathematics.

However, in Turkish society, girls spent more time in indoor activities, and because of this, females might spend more time on schoolwork than boys. In spite of these deficiencies, these findings are hopeful for Turkey. However, it is difficult to generalize these findings for all of Turkey. These findings may enable us to have some ideas about the other regions in Turkey. The present study examined the role of gender in PSTs' mathematics achievement and beliefs about mathematics in one university in southeast Anatolia. Future research should be conducted in other regions to obtain more reliable information about both preservice and inservice teachers' beliefs about mathematics and different level students' mathematics achievement such as master's and doctoral degrees. In this study, quantitative measures were used. In the future, qualitative methods, such as open-ended question prompts, focus groups, and/or one-to-one interviews should be used for supported the present studies' findings and strengthen the study.

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Author's Notes

Keywords: Gender differences; gender stereotypes; belief; mathematics performance; preservice teachers.

PROBLEMS section

Ted Eisenberg, *Section Editor*

This section of the Journal offers readers an opportunity to exchange interesting mathematical problems and solutions. Please send them to Ted Eisenberg, Department of Mathematics, Ben-Gurion University, Beer-Sheva, Israel or fax to: 972-86-477-648. Questions concerning proposals and/or solutions can be sent e-mail to eisenbt@013.net. Solutions to previously stated problems can be seen at http://ssmj.tamu.edu.

Solutions to the problems stated in this issue should be posted before June 15, 2011

• **5158:** *Proposed by Kenneth Korbin, New York, NY*

Given convex cyclic quadrilateral $ABCD$ with integer length sides $\overline{AB} = \overline{BC} = x$, and $\overline{CD} = \overline{DA} = x+1$.

Find the distance between the incenter and the circumcenter.

• **5159:** *Proposed by Kenneth Korbin, New York, NY*

Given square $ABCD$ with point P on diagonal $\overline{AC}$ and with point Q at the midpoint of side $\overline{AB}$.

Find the perimeter of cyclic quadrilateral $ADPQ$ if its area is one unit less than the area of square $ABCD$.

• **5160:** *Proposed by Michael Brozinsky, Central Islip, NY*

In Cartesianland, where immortal ants live, there are n (where $n \geq 2$) roads $\{l_i\}$ whose equations are

$$l_i : x\cos\left(\frac{2\pi i}{n}\right) + y\sin\left(\frac{2\pi i}{n}\right) = i, \text{ where } i = 1, 2, 3, \ldots n.$$

Any anthill must be located so that the sum of the squares of its distances to these n lines is $\frac{n(n+1)(2n+1)}{6}$. Two queen ants are (im)mortal enemies and have their anthills as far apart as possible. If the distance between these queens' anthills is 4 units, find n.

• **5161:** *Proposed by Paolo Perfetti, Mathematics Department, University of Rome, Italy*

It is well known that for any function $f: \Re \to \Re$, continuous or not, the set of points on the y-axis where it attains a maximum or a minimum can be at most denumerable. Prove that any function can have at most a denumerable set of inflection points, or give a counterexample.

• **5162:** *Proposed by José Luis Díaz-Barrero and José Gibergans-Báguena, Barcelona, Spain*

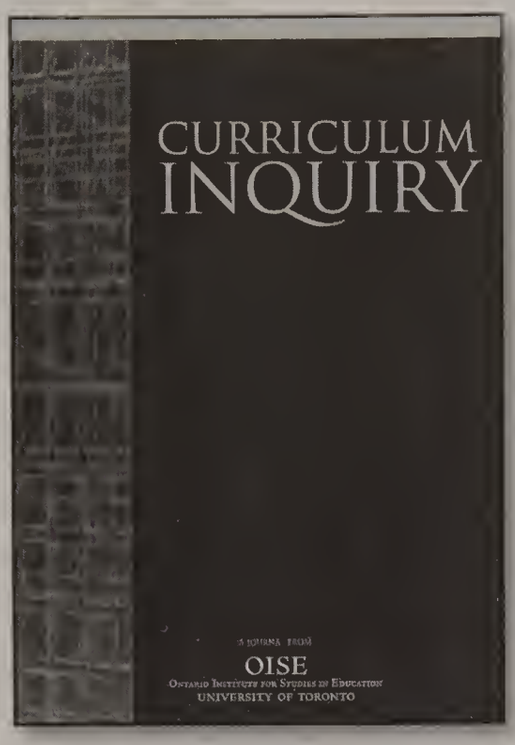
Let a, b, c be the lengths of the sides of an acute triangle ABC. Prove that

$$\sqrt{\frac{b^2+c^2-a^2}{a^2+2bc}} + \sqrt{\frac{c^2+a^2-b^2}{b^2+2ca}} + \sqrt{\frac{a^2+b^2-c^2}{c^2+2ab}} \leq \sqrt{3}.$$

• **5109:** *Proposed by Pedro H. O. Pantoja, Lisbon, Portugal*

Prove that for all n

$$\int_0^\infty \frac{x^n}{2}\left(\coth\frac{x}{2}-1\right)dx=\sum_{k_1=1}^{\infty}\cdots\sum_{k_n=1}^{\infty}\frac{1}{k_1\cdots k_n(k_1+\cdots+k_n)}.$$



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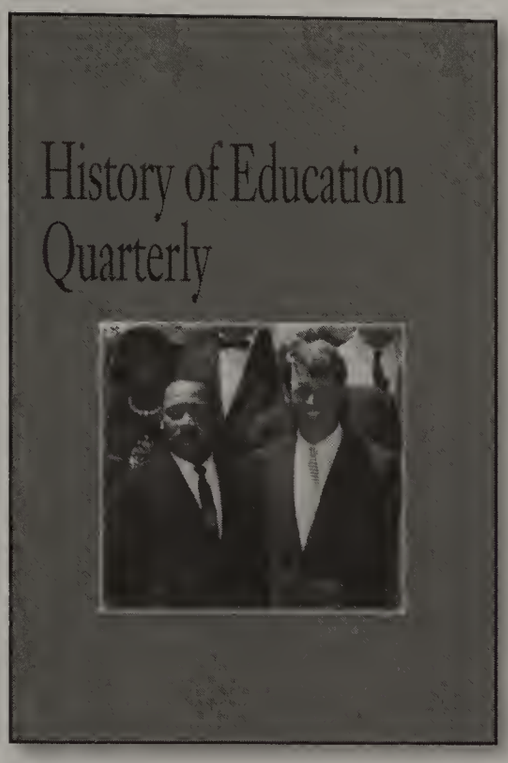

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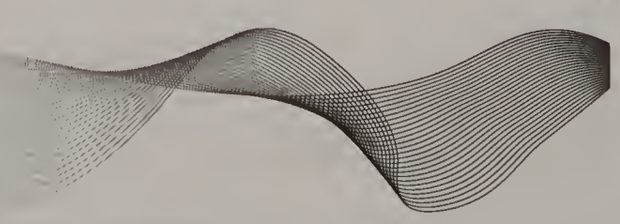

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Research manuscripts only:

Design and methodology
Analyses of data
Conclusions based on results
Results related to professional practice and literature
Enough information to enable replication (quantitative)

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IN THIS issue

Guest Editorial

Is STEM Misspelled?
Alan Zollman

STEM is the new, trendy acronym in education. STEM, of course, refers to Science, Technology, Engineering, and Mathematics. STEM Education relates to the oft-mentioned dual problems of (a) the need for more scientists, technologists, engineers, and mathematicians; and (b) the pipeline supply needed for more graduates in these content areas.

Analysis of Environmental and General Science Teaching Efficacy Among Instructors With Contrasting Class Ethnicity Distributions: A Four-Dimensional Assessment
Christine Moseley, Bryan Taylor

The context and nature of teacher-efficacy beliefs provide a method upon which to explore science teachers' perceptions of their teaching effectiveness and student achievement as a function of ethnicity. Promotion of a more in-depth knowledge of science-teaching efficacy requires cross-sectional and longitudinal investigations. In this study, a bidisciplinary four-dimensional assessment is utilized to measure personal teacher efficacy, outcome expectancy, classroom management (CM), and student engagement (SE).

Major findings from this study conclude that science-teaching efficacy was markedly lower for science teachers with high-minority class ethnicity distribution (CED) when compared with efficacy levels of teachers with high-nonminority CED. Additionally, when examining efficacy dimensions separately, markedly lower-mean efficacy dimension responses were consistent for teachers with high-minority CED; however, only CM and SE were considered statistically different. Results were consistent for both the environmental and general science disciplines.

A Teacher's Journey With a New Generation Handheld: Decisions, Struggles, and Accomplishments
S. Aslı Özgün-Koca, Michael Meagher, Michael Todd Edwards

In this technology-oriented age, teachers face daily decisions regarding the use of advanced digital technologies—graphing calculators, dynamic geometry software, blogs, wikis, podcasts, and the like—to enhance student mathematical understanding in their classrooms. In this case study, the authors use the Technological, Pedagogical, and Content Knowledge (TPACK) model in conjunction with a five-stage developmental model that can be used to describe growth in TPACK, to describe the initial attempts of a teacher, Jane, to develop TPACK as she learns and attempts to integrate an advanced teaching technology into her classroom, namely the *TI-Nspire* graphing calculator. The study tracks her struggles to reconcile some traditional beliefs about how students learn with her desire to be responsive to what she perceives as affordances of advanced digital technologies. Main data collection methods were journal writing, observations, document analysis, and interviews. Using the five-stage developmental model, we saw that this experience helped Jane to move among different stages. This study showed that the TPACK model with the five-stage developmental model can be a beneficial tool for researchers to study teachers' professional growth and is also a valuable tool for teachers to reflect on their own growth.

Content Knowledge, Attitudes, and Self-Efficacy in the Mathematics New York City Teaching Fellows (NYCTF) Program
Brian R. Evans

The purpose of this study was to understand the mathematical content knowledge new teachers have both before and after taking a mathematics methods course in the New York City Teaching Fellows program. Further, the purpose was to understand the attitudes toward mathematics and concepts of self-efficacy that teaching fellows had over the course of the semester. The sample included 42 new teaching fellows who were given a mathematics content test, attitudes toward mathematics questionnaire, and teaching self-efficacy questionnaire at the beginning and end of the semester. Further, the teachers kept teaching and learning journals. Findings revealed a significant increase in both mathematical content

knowledge and positive attitudes toward mathematics. Additionally, teaching fellows were found to have positive attitudes and high self-efficacy at the end of the semester, and relationships were found between attitudes and self-efficacy. Finally, teaching fellows generally found that classroom management was the biggest issue in their teaching, and that problem solving and numeracy were the most important topics addressed in their learning. Future studies should address self-efficacy differences between preservice and in-service teachers and the effects of alternative certification teacher knowledge, attitudes toward mathematics, and self-efficacy on students in the classroom.

Preservice Teachers' Beliefs and Attitude About Teaching and Learning Mathematics Through Music: An Intervention Study

Song A. An, Tingting Ma, Mary Margaret Capraro

This article presents exploratory research investigating the integration of music and a mathematics lesson as an intervention to promote preservice teachers' attitude and confidence, and extend their beliefs toward teaching mathematics integrated with music. Thirty students were randomly selected from 64 preservice teachers in a southern university. A 90-minute mathematics lesson integrated with a music composition activity was taught by the first author. Pre- and postquestionnaires were provide to evaluate the change in preservice teachers' attitude and beliefs toward mathematics. The results demonstrated that the mathematics lesson integrated with music had a positive effect on preservice teachers' attitude and beliefs toward mathematics teaching and learning.

Keywords: Mathematics; music; connection; attitude; beliefs; intervention.

Piaget's Logic of Meanings: Still Relevant Today

Michael James Wavering

In his last book *Toward a Logic of Meanings*, Jean Piaget describes how thought can be categorized into a form of propositional logic, a logic of meanings. The intent of this paper is to offer this analysis by Piaget as a means to understand the language and teaching of science. By using binary propositions, conjunctions, and disjunctions, a table of binary operations is used to analyze the structure of statements about conclusions drawn from observations of science phenomena. Two examples from science content illustrate how the logic of binary propositions is used to symbolize reasoning typical of secondary-school science students. The content areas are the period of a pendulum and the Archimedes' Principle, which were chosen based on observations in secondary science classrooms. The analyses of the student responses in these two observations demonstrate the commonalities of arguments used by students of science as they try to make sense of observations. The analysis of students' reasoning demonstrates that Piaget's logic of meanings is a useful and relevant tool for science educators' understanding of the syntactical aspects of pedagogical content knowledge.

Alan Zollman
Northern Illinois University

Is STEM Misspelled?

STEM is the new, trendy acronym in education. STEM, of course, refers to Science, Technology, Engineering, and Mathematics. STEM Education relates to the oft-mentioned dual problems of (a) the need for more scientists, technologists, engineers, and mathematicians; and (b) the pipeline supply needed for more graduates in these content areas.

But what about Medicine? With our expanding health-care system, we need more people in the medical profession also. Medical professions need mathematics, science, and technology knowledge and skills. Is there not a second "M" missing in STEM?

And what about Education? Is an "E" missing, too? Do we not need educators, at all levels kindergarten through college, who have a strong background in mathematics, science, and technology? There is a continuing shortage of well-qualified mathematics, chemistry, physics, and technology teachers in education. So, should it be spelled STEEMM, or maybe STEMME?

Hold on! Should not a "Q" be in there also? It is not enough that a student takes four years of mathematics and three years of science (that includes a lab) in high school. I once had a student who took "Calculus I" four times, but according to the Department of Education *Toolbox Revisited* (Adelman, 2006), it is the quality and the rigor of those courses taken. So, we also need an "R" for rigor and a "Q" for quality. Now what do we have, STEMMER-Q?

Hey, do we not want *all students* to have this knowledge? Research has shown that up to 80% of entering college students admit that they are not certain what their major will be. By the time they graduate, over 50% of college students change their major at least once. Some change several times (Leonard, 2010). And, according to the U.S. Department of Labor, the average U.S. worker changes careers three to five times during their lifetime. Workers between the ages of 18 and 38 change jobs an average of 10 times (McKay, 2006).

So, we need more than STEM majors—we need everyone to be literate in the STEM areas. Literacy means skills beyond reading and writing—according to Bloom's Taxonomy (1956)—which are the skills needed to be able to recognize, explain, apply, analyze, synthesize, and evaluate. We need all students to actively and recurrently (1) decode; (2) conceptualize; and (3) apply mathematics, science, and technology skills and knowledge (Cappetta & Zollman, 2009). This is the synthesis of STEM Literacy—scientific literacy, technology literacy, engineering literacy, and mathematical literacy. Where scientific literacy is a means for participating in learning, technological literacy is a means for analyzing data, engineering literacy is a means for applications to the real world, and mathematical literacy is a means for problem solving (National Governors Association, 2007). Now, do we need to add an "L" to the acronym? And maybe it should be STEAM? Shouldn't we include the Arts also?

We now have STEM Institutes, STEM Conferences, and STEM Journals. Just how new is STEM? Look on the spine of this issue of *School Science and Mathematics*—it says volume 111. Since 1901, the School Science and Mathematics Association (SSMA) has been an inclusive, professional community to unify researchers and educators to promote research, scholarship, and practice for the improvement and integration of school science and mathematics. Yes, SSMA is just 11 decades ahead of this trend.

Acronyms change every few years in education. Will STEM be around in 10 years? I doubt it. But I suspect that the SSMA may be here for another 110 years. So, if we spell STEM as SSMA, I think we will be OK.

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Author's Note

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Analysis of Environmental and General Science Teaching Efficacy Among Instructors with Contrasting Class Ethnicity Distributions: A Four-Dimensional Assessment

Christine Moseley
University of Texas at San Antonio

Bryan Taylor
United States Army Corps of Engineers

The context and nature of teacher efficacy beliefs provide a method upon which to explore science teachers' perceptions of their teaching effectiveness and student achievement as a function of ethnicity. Promotion of a more in-depth knowledge of science teaching efficacy requires cross-sectional and longitudinal investigations. In this study, a bi-disciplinary four-dimensional assessment is utilized to measure personal teacher efficacy, outcome expectancy, classroom management (CM), and student engagement (SE).

Major findings from this study conclude that science teaching efficacy was markedly lower for science teachers with high minority class ethnicity distribution (CED) when compared with efficacy levels of teachers with high nonminority CED. Additionally, when examining efficacy dimensions separately, markedly lower mean efficacy dimension responses were consistent for teachers with high minority CED; however, only CM and SE were considered statistically different. Results were consistent for both the environmental and general science disciplines.

Teacher efficacy has been defined as "the extent to which the teacher believes he or she has the capacity to affect student performance" (Berman, McLaughlin, Bass, Pauly, & Zellman, 1977, p. 137). Thus, the context and nature of teacher efficacy can provide a method to explore teachers' perceptions of and beliefs about their teaching effectiveness and student achievement as a function of ethnicity (Pajares, 1996). Bryan and Atwater (2002) report that teacher beliefs are directly related to teaching practices when working with diverse student populations. They state that recognizing and identifying beliefs should be an important aspect of teacher preparation as teacher beliefs influence teaching practices, and these practices can cause biased treatment toward students depending upon culture and ethnicity.

Promotion of a more in-depth knowledge of teacher efficacy requires cross-sectional and longitudinal investigations (Pajares, 1996). Currently, there is a limited amount of cross-sectional teacher efficacy data available that compare environmental and general science teaching efficacy among teachers with contrasting class ethnicity distributions (CED) (minority versus nonminority). Therefore, the purpose of this study was to utilize a bi-disciplinary four-dimensional assessment to measure personal teacher efficacy (PTE), outcome expectancy (OE), classroom management (CM), and student engagement (SE). The following research questions were addressed:

- Is there a significant difference in mean environmental and general science teaching efficacy scores for teachers with contrasting CED (minority versus nonminority)?
- When comparing environmental and general science teaching efficacy dimensions (PTE, OE, CM, and SE), do mean efficacy response scores differ for teachers with contrasting CED (minority versus nonminority)?

Background

Self-efficacy, a component of social learning theory, is a psychological construct concerned with judgments about how well an individual can organize and execute specific courses of action (Bandura, 1977). Bandura claims that efficacy expectations are a major determinant of an individual's choice of activities and the amount of effort that is expended and sustained in the performance of those activities. Two critical components of self-efficacy recognized in Bandura's

social learning theory are the beliefs in one's ability to successfully perform the behavior (efficacy expectation) and that the performance of the behavior will have a desirable outcome (response–outcome expectancy).

Examination of self-efficacy in relation to teaching has been the focus of study by several researchers (Ashton & Webb, 1986; Enochs & Riggs, 1990; Gibson & Dembo, 1984; Guskey, 1988). Bandura (1977) defines personal self-efficacy as a person's perception of his/her ability to perform a behavior (Enoch & Riggs). Gibson and Dembo suggest sense of efficacy as a variable accounting for variations in teaching ability. They created the Teacher Efficacy Scale which contains two subscales, PTE and general teaching efficacy (GTE), similar to Bandura's two critical components of self-efficacy. Gibson and Dembo suggest that PTE corresponds to Bandura's efficacy expectation, where teachers' behaviors in classrooms are highly influenced by their own perceptions of their ability to teach. GTE corresponds to resource–outcome expectancy in which teachers believe their teaching strategies are effective toward student learning. Tracz and Gibson (1986) further identify efficacy as an important variable in teacher's effectiveness. Their study shows that a teacher's sense of efficacy relates significantly to student achievement.

Effective teachers tend to have a high sense of efficacy about their own teaching. They believe that their teaching will cause almost all of their students to learn (Berman & McLaughlin, 1977). A high sense of teaching efficacy has been identified as one of the teacher dispositions associated with effective practice and directly related to several variables, such as teachers' adoption of innovation (Berman & McLaughlin; Guskey, 1982; Smylie, 1988), positive attitudes about teaching (Guskey), teachers' CM strategies (Ashton & Webb, 1986), teachers' instructional strategies (Wagler & Moseley, 2006), student motivation (Midgely, Feldlaufer & Eccles, 1989), and student achievement (Guskey, 1982, 1988). Teacher efficacy has also been shown to be negatively related to teacher attrition (Glickman & Tamashiro, 1982) and stress (Smylie).

Science teaching efficacy has been identificd as an influential construct in science teaching (Enochs & Riggs, 1990; Riggs, 1988). According to Brickhouse (1989), in science education, teacher beliefs are congruent with their mode of instruction. Strong teaching efficacy results in more stringent planning and organization (Allinder, 1994), while weak teaching efficacy has been shown to substantially lower student achievement levels (King, Shumow, & Lietz, 2001). Teacher efficacy has been found to be a determinant of students' achievement, motivational levels, and confidence (Tschannen-Moran & Hoy, 2001).

Instruments have been developed to measure teacher efficacy within specific curriculum areas. Riggs and Enochs (1990) developed the Science Teaching Efficacy Belief Instrument (STEBI) to measure teacher efficacy in science. The authors identified two uncorrelated factors within STEBI, which they named personal science teaching efficacy (PTSE) and science teaching outcome expectancy (STOE). Exploring an even greater level of specificity, Rubeck and Enochs (1991) distinguished teacher efficacy in chemistry from teacher efficacy in science. Similar instruments have been created to measure teacher efficacy in mathematics (Enochs, Smith, & Huinker, 2000), special education (Coladarci & Breton, 1997), and environmental education (Sia, 1992).

Ethnicity, perceived intelligence, and academic performance have been shown to influence teachers' expectations of individual student achievement (Rodney, Perry, Parsonson, & Hrynuik, 1986). Basic typecasting and perceived biases affect how people make decisions and solve problems (Anderson, Grene, & Loewen, 1988). Even experienced teachers have been shown to differentiate according to ethnicity which directly affects student outcomes (Melnick & Raudenbusch, 1986).

The current situation involving science education in minority high schools is incompatible with that of its nonminority counterparts (King et al., 2001). Longitudinal research provides evidence that many teachers in economically depressed minority schools believe their students are incapable of extracting higher order principles from scientific disciplines, thus abandoning higher order methodology (Beane, 1988). According to the National Science Education Standards (National Research Council, 1996), an effective science teacher should view all students as capable of useful contributions during science learning, and equity should pervade all aspects of science learning.

Successful instruction of minorities has proved to be the result of high classroom expectations and positive beliefs about student achievement by their teachers (Ladson-Billings, 1994). Negative preconceptions from teachers based on racial and/or socioeconomic factors impair minority students' motivation and

achievement (Payne, 1994). Despite findings of ill-prepared science teachers and decreasing student achievement in minority schools, very little empirical data have probed causal links related to minority student achievement in science (King et al., 2001).

There are numerous variables other than science teacher efficacy that may impede minority success in science; these include students' own self-efficacy, socioeconomic factors, non-attainable academic resources, and familial structure (Bandura, 1986; Pajares, 1996). However, low science teacher efficacy has been shown to substantially lower student outcomes and achievement levels (Ashton & Webb, 1986; Hoy, 2000; King et al., 2001). Thus, the purpose of this research was to assess environmental and general science teacher efficacy for instructors with contrasting CED (minority versus nonminority).

Methodology

Instrumentation

Efficacy beliefs are task or context specific (Tschannen-Moran, Woolfolk-Hoy, & Hoy, 1998) in that teaching efficacy within a single context, such as science, may not affect teaching efficacy concerning another teaching responsibility, such as mathematics or chemistry. Thus, this study chose to assess environmental and general science teaching efficacies separately. Although environmental teaching efficacy (EE) has become interdisciplinary in its curricular approaches and is being implemented within varying disciplines (Middlestadt, Ledsky, & Sanchack, 1999; Sasse, 1997), examination of teacher efficacy as it pertains to EE curriculum has been minimal.

The Environmental and General Science Teacher Efficacy Assessment (EGSTEA) used in this study was modified from the Environmental Education Efficacy Belief Instrument (EEEBI; Sia, 1992), the STEBI (Riggs & Enochs, 1990), and Factors 2 and 3 from the Ohio State Teacher Efficacy Scale (OSTES; Tschannen-Moran & Hoy, 2001). Modified from the STEBI, the EEEBI reflects future environmental education teaching beliefs, and contains 23 statements addressing personal environmental teaching efficacy and environmental teaching OE. The EEEBI utilizes a 5-point Likert-scale response format that ranges from strongly agree (5) to strongly disagree (1). The validity of this instrument is reportedly high (Sia). Moseley, Reinke, and Bookout (2002) reported high instrument reliability marked by a Guttman split-half coefficient of .9132.

The STEBI contains 23 statements addressing PSTE and STOE. The STEBI utilizes the same Likert scale response format as previously mentioned. Negatively phrased statements are reverse-coded prior to analysis of collected data. The STEBI is a reliable and valid instrument with a coefficient alpha of .92 for the PSTE and .77 for the STOE, as reported by Riggs and Enochs (1990).

Tschannen-Moran (2000) defined tasks that were relevant to teaching in the construction of OSTES. It is a nine-option Likert-type scale with response choices ranging from nothing (1) to a great deal (9). The OSTES contains four subcategories: overall efficacy, classroom management student engagement, and instructional strategies. Factors 2 and 3 of the OSTES were chosen to be included in the instrument developed for this study. Factor 2 contains eight questions that address CM, and Factor 3 contains eight questions that address SE. Tschannen-Moran and Hoy (2001) reported high reliabilities for these two factors, with reported coefficient alphas of .90 and .87 for Factors 2 and 3, respectively.

Modified from the above validated research instruments, the EGSTEA employed a bi-disciplinary, four-dimensional assessment to examine both environmental and general science efficacy. The first dimension, PTE for environmental and general science, modified from the STEBI and the EEEBI, was embedded within questions 2, 3, 5, 6, 8, 12, and 17–23. The second dimension, OE for environmental and general science, modified from the STEBI and the EEEBI, was embedded within questions 1, 4, 7, 9–11, and 13–16. The third dimension, CM, modified from the OSTES, was embedded within questions 26–33. Finally, the fourth dimension, SE, modified from the OSTES, was embedded with questions 34–41.

Reliability for the EGSTEA was determined to be high with a Cronbach's alpha of .952 (EE) and .951 (general science efficacy [GSE]) for the entire instrument. Reliability for subscales (efficacy dimensions) was determined to be high with Cronbach's alphas of .632 (EE) and .611 (GSE) for OE, .958 (EE) and .957 (GSE) for PTE, .851 for CM, and .865 for SE.

Participants

Research participants consisted of a convenient sample of high and middle school science teachers employed within various school districts statewide. A single stage sampling procedure was utilized. Contact information of science teachers were obtained through district Web sites and State Department science

education contacts. Teachers were solicited via phone for their participation, and research instruments were distributed accordingly. Also, research instruments were distributed to Science Department heads and/or school science curriculum points of contact for distribution to science teachers in their schools. Forty science teachers participated as marked by the submission of 40 completed research questionnaires via mail.

The cumulative number of students taught per day by all 40 participants totaled 4,116 students. Of these students, 401 were Hispanic (9.7%), 1,348 were Black (32.7%), 2,016 were White (48.9%), 42 were Asian (1%), 216 were American-Indian (5.2%), and 99 were considered an ethnicity other than those listed (2.4%). For the purposes of this study, the term "minority" referred to students who are Hispanic, Black, or American-Indian; the term "nonminority" referred to students who are from the White only. Data were stratified based on CED (minority versus nonminority). CED was based on greater than 50% ethnicity majority. Because of low variable numbers, Asian students and/or other ethnicities were not utilized in criteria for the determination of CED in this study.

Of the 40 research participants in this study, 22 teachers had high minority student populations; classrooms labeled "high minority CED" contained a mean average of 74% minority students. The remaining 18 teachers had high nonminority student populations; classrooms labeled "high nonminority CED" contained a mean average of 72% nonminority students. Teacher gender consisted of 18 male teachers and 22 female teachers. Science teacher demographics consisted of White (31), White/American Indian (2), American Indian (5), and Black (2). There were 17 teachers having greater than 10 years of teaching experience; 23 teachers had less than 10 years of teaching experience. There were 14 teachers teaching at the middle school grade level and 26 teachers teaching at the high school grade level. For the purpose of this study, middle school designation ranged from sixth to eighth grade and/or sixth to ninth grade if the ninth grade designation was associated with a middle school. High school ranged from ninth to 12th grades and/or 10th to 12th grades depending on the above ninth grade designation.

Results

Teachers with high percent minority CED exhibited significantly lower ($p < .0001$) environmental and general science efficacy scores when compared with

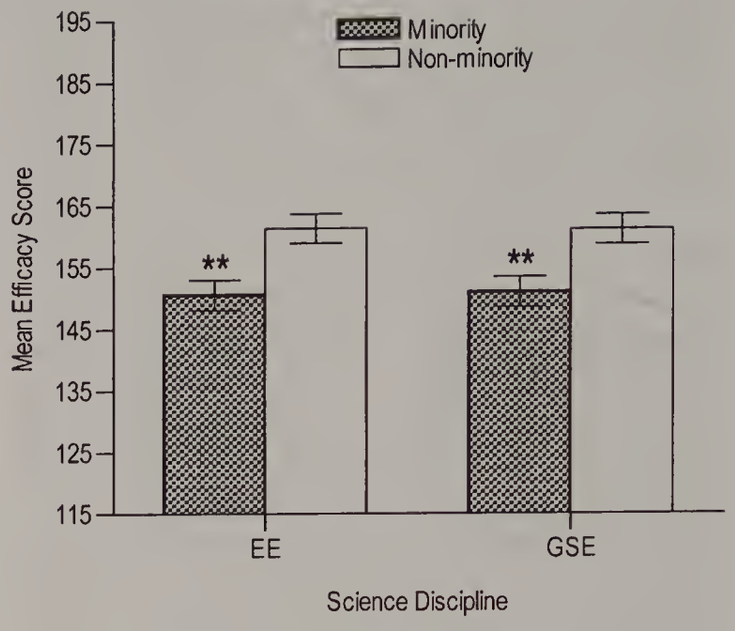

Figure 1. Effect of CED (minority $n = 22$ versus nonminority $n = 18$) and science discipline (environmental versus general) on mean teacher efficacy score.
Note. Asterisks represent mean efficacy scores significantly lower (**$p < .01$) than paired group means.

Table 1
Effect of Class Ethnicity Distribution and Science Discipline (Environmental and General) on Mean Efficacy Score

Source	*df*	*SS*	*MS*	*F*	*p*
CED	1	2,146	2,146	18.01	.00
Science	1	.07	.07	.00	.98
Interaction	2.17	2.17	.02	.89	
Residual	76	9,057	119.20		

df – degree of freedom; SS – Sum of squares; MS – Mean square; F – Fisher's F ratio.

that of teachers with high percent nonminority CED (Figure 1). Two-way analysis of variance (ANOVA; Table 1) revealed that CED had a significant effect on environmental and general science efficacy scores (F [1, 76] = 18.01, $p > .01$). In Table 2, when differences between EE and CED scores ($t = 3.096$, $p < .01$) and general science efficacy (GSE) and CED scores ($t = 2.906$, $p < .01$) were compared, there was not a statistically significant difference. This is in contrast to Tschannen-Moran, Woolfolk-Hoy, and Hoy's (1998) assertion that efficacy is task or context specific.

Table 2
Summary of Bonferroni Post Hoc Tests for Table 1 Two-way ANOVA

Science	Minority	Nonminority	*t*	*p*
EE	150.60	161.30	3.10	.00
GSE	150.90	160.9	2.91	.00

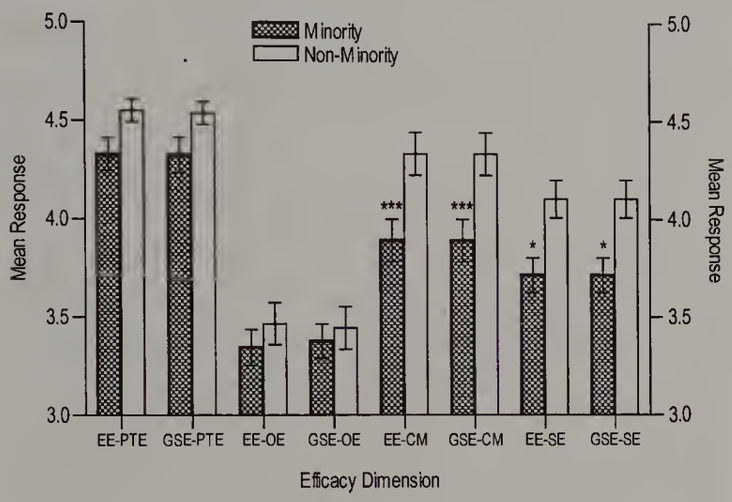

Figure 2. Effect of class ethnicity distribution (minority *n* = *22* versus nonminority *n* = *18*) and efficacy dimension (personal teaching efficacy, outcome expectancy, classroom management, and student engagement) on mean environmental and general science efficacy responses.
Note. Asterisks represent mean efficacy scores significantly lower (***$p < .001$ / *$p < .05$) than paired group means.

Discussion

Teachers with high percent minority CED exhibited significantly lower CM and SE scores when compared with that of teachers with high percent nonminority CED (Figure 2). Two-way ANOVA of CED and efficacy dimensions (Table 3) revealed that CED had a significant effect on mean EE and GSE responses for CM and SE ($F[1, 304] = 36.03, p < .0001$). In Table 4, Bonferroni posttests revealed that teachers with high percent minority CED exhibited significantly lower efficacy responses for CM ($p < .01$) and SE ($p < .05$) than that of teachers with high nonminority CED. Consequently, as indicated in Figure 2, mean efficacy responses were consistently higher for teachers with high percent nonminority CED for all four dimensions of both EE and GSE when compared with that of teachers with high minority CED. However, there was

Table 3
Effect of CED and Efficacy Dimension on Mean Environmental and General Science Efficacy Scores

Source of Variation	*df*	*SS*	*MS*	*F*	*p*
CED	1	6.45	6.45	36.03	.00
Efficacy dimension	7	44.06	6.29	35.15	.00
Interaction	7	1.52	.22	1.21	.30
Residual (error)	304	54.44	.18		

df – degree of freedom; SS – Sum of squares; MS – Mean square; F – Fisher's F ratio.

not a statistically significant difference for the efficacy dimensions of PTE or OE when comparing efficacy responses for teachers with contrasting CED; these results were consistent for both the general and environmental science disciplines.

Additionally, two-way ANOVA also revealed that efficacy dimension had a significant effect on teacher efficacy responses (Table 5). When GSE and EE responses were examined for teachers with high minority CED only, PTE responses were the highest of the four efficacy dimensions, followed by CM, SE, and OE, respectively. Within minority classrooms, general science teacher mean efficacy responses for PTE were significantly higher than mean efficacy responses for OE ($t = 7.429, p < .001$), CM ($t = 3.395, p < .01$), and SE ($t = 4.775, p < .001$); general science mean OE efficacy responses were significantly lower than SE ($t = 2.654, p < .05$) and CM ($t = 4.035, p < .001$) efficacy scores. Within minority classrooms, OE and SE were significantly lower (GSE: $t = 2.654, p < .05$; EE: $t = 2.904, p < .01$) than efficacy responses for both PTE and CM (GSE: $t = 3.395, p < .01$; EE: $t = 3.422, p < .01$). There was not a significant difference (GSE: $t = 1.381, p > .05$; EE: $t = 1.381, p > .05$) between efficacy responses for CM and SE. When efficacy responses were examined for teachers with high percent nonminority students only, the results were consistent with that of minority classrooms with the exception of *p* values: PTE was only significantly higher at the .05 level for CM and at the .01 level for SE; OE was significantly lower than SE at the .001 level.

Discussion

Overall, teaching efficacy levels of teachers with high minority CED were consistently lower than that

Table 4
Summary of Bonferroni Post Hoc Tests for Table 3 Two-way ANOVA

Efficacy Dimension	Minority		Nonminority		*t*	*p*
	M	*SD*	*M*	*SD*		
EE-PTE	4.33		4.55		1.66	>.05
GS-PTE	4.33		4.54		1.59	>.05
EE-OE	3.35		3.47		.90	>.05
GS-OE	3.38		3.44		.50	>.05
EE-CM	3.89		4.33		3.28	<.01
GS-CM	3.89		4.33		3.28	<.01
EE-SE	3.72		4.10		2.89	<.05
GS-SE	3.72		4.10		2.89	<.05

of teachers with high nonminority CED. Traditionally, teachers of minority students have believed that science reasoning and application were too challenging for their students (King et al., 2001), and that minorities lacked the ability to extract higher order principles from scientific disciplines (Beane, 1988). The diminished teaching efficacy exhibited from teachers with high minority CED in this study is consistent with these findings.

Teaching efficacy affects teachers' efforts and the goals they set for their classroom (Tschannen-Moran & Hoy, 2001). Teachers with high nonminority CED showed teaching efficacy levels indicative of their abilities to get their students to value learning and motivate students who show low interest in science learning. However, the low teaching efficacy exhibited for teachers with high minority CED was indicative of uncertainty in their abilities to foster value for learning in their students, motivate students who show low interest, or get through to the most difficult students. The extent of teachers' confidence in their ability to affect their students' learning is a determining factor of student performance in their classroom (Tschannen-Moran & Hoy).

Although mean OE responses exhibited from teachers with high minority CED were consistently lower, teachers with high minority CED and teachers with high nonminority CED all exhibited low mean OE responses for both environmental and general science curricula. This marks a consistent lack of confidence and belief in all students' abilities to learn science and should be a point of concern for all science educators. Although teachers with high nonminority CED exhibited low mean OE responses, they nevertheless exhibited markedly high mean PTE, CM, and SE responses to counteract this deficit in student expectations, unlike that of teachers with high minority CED who had consistently lower OE, PTE, CM, and SE responses.

Literature has suggested that successful instruction of minorities results from stringent outcome expectations supported through positive beliefs (Ladson-Billings, 1994). It has also been suggested that lowered expectations based on racial factors impair the process by which minority students are motivated and distort the way their achievements are shaped (Payne, 1994). In this study, it was demonstrated that both teachers with high minority as well as teachers with high nonminority CED exhibited relatively low OE responses when related to student outcomes in environmental and general science. This indicates that all respondents (science teachers) question whether their students have the ability to learn science. Although this notion is indeed more prevalent in high minority science classrooms, it does have some bearing on OE beliefs in all science classrooms as demonstrated in this research.

According to findings herein, CM and SE are the two major factors in the diminished efficacy of teachers with high minority CED. A link exists between teacher efficacy and the conditions present that impinge on the successful completion of work

Table 5
Summary of Bonferroni Post Hoc Tests for Two-way ANOVA of Efficacy Dimension and CED

CED	GSE-PTE	GSE-OE	*t*	*p*
Minority	4.33	3.38	7.43	<.001
Nonminority	4.54	3.44	7.76	<.001
	GSE-PTE	GSE-CM	*t*	*p*
Minority	4.325	3.892	3.395	<.01
Nonminority	4.538	4.333	1.454	<.05
	GSE-PTE	GSE-SE	*t*	*p* value
Minority	4.325	3.716	4.775	<.001
Nonminority	4.538	4.104	3.079	<.01
	GSE-OE	GSE-CM	*t*	*p* value
Minority	3.377	3.892	4.035	<.001
Nonminority	3.444	4.333	6.302	<.001
	GSE-OE	GSE-SE	*t*	*p* value
Minority	3.377	3.716	2.654	<.05
Nonminority	3.444	4.104	4.677	<.001
	GSE-CM	GSE-SE	*t*	*p* value
Minority	3.892	3.716	1.381	>.05
Nonminority	4.333	4.104	1.625	>.05
	EE-PTE	EE-OE	t	*p* value
Minority	4.329	3.345	7.706	<.001
Nonminority	4.551	3.467	7.689	<.001
	EE-PTE	EE-CM	*t*	*p* value
Minority	4.329	3.892	3.422	<.01
Nonminority	4.551	4.333	1.545	<.05
	EE-PTE	EE-SE	*t*	*p* value
Minority	4.329	3.716	4.803	<.001
Nonminority	4.551	4.104	3.17	<.01
	EE-OE	EE-CM	*t*	*p* value
Minority	3.345	3.892	4.284	<.001
Nonminority	3.467	4.333	6.144	<.001
	EE-OE	EE-SE	*t*	*p* value
Minority	3.345	3.716	2.904	<.01
Nonminority	3.467	4.104	4.52	<.001
	EE-CM	EE-SE	*t*	*p* value
Minority	3.892	3.716	1.381	<.05
Nonminority	4.333	4.104	1.625	<.05

goals (Metz, 1978). Although all four dimensions of efficacy (PTE, OE, CM, and SE) were consistently lower for teachers with high minority CED, markedly low mean CM and SE responses were evidenced for teachers with high minority CED. This diminished CM and SE affects teachers' decisions concerning daily assignments and work goals that are vital to effective classroom operations (Rosenholtz, 1987). The perception of loss of classroom control increases stress levels, thus decreasing career satisfaction, resulting in a lowered sense of self-efficacy (Rosenholtz). This, along with low OE beliefs, has the potential to result in diminished learning for students.

Interestingly, when examining mean efficacy dimensions and grade level, OE responses for middle school science teachers were higher than that of high school science teachers, suggesting that a decrease in OE beliefs for science is proportional to student grade promotion. PTE levels were not markedly different when comparing grade level. However, middle school level responses for CM and SE were lower than that of high school level science teachers.

Bandura (1986) suggests a theory that teacher efficacy is most affected within the early years of instruction; these years are the most pivotal to the development of a teacher's efficacy belief system. Efficacy levels for more experienced teachers, although lower for teachers with high minority CED, were not drastically different from teachers with high nonminority CED. However, teachers with less than 10 years of experience exhibited significantly lower efficacy levels when their CED was high minority when compared with that of nonminority. Perhaps science teacher efficacy beliefs and student perceptions are not static but may be affected by teaching experience.

Teachers with high nonminority CED reported utilizing an outdoor classroom more than teachers with high minority CED. The neglect in utilization of outdoor classroom resources by teachers with high minority CED should be highlighted as a concern of interest. Interestingly, more teachers with more years of teaching experience were less willing to utilize outdoor classrooms.

Implications

The consistently low teaching efficacy scores, especially OE, for science teachers with high minority CED should be a critical point of concern for our science education policymakers, administrators, and

teachers. The issue of lower science teacher efficacy among science educators with high minority CED must be addressed. These teachers feel they have the necessary knowledge, ability, and skills to teach science as evidenced in high PTE. Although PTE is lower than in teachers with high nonminority CED, this perception was clearly much higher than that of the other dimensions (OE, SE, and CM) measured.

Professional development initiatives should be promoted, not only to target methods for enhancing science curriculum, but also to target practices that enhance teacher efficacy, especially when related to OE, CM, and SE for teachers with high minority CED. Teachers should not let students' behaviors, cultural expressions, or sociological and/or economic problems delegate what components of their daily lesson will be presented. Professional development for minority student instruction should foster teacher acclimation with their students' communities and families so that teachers will be able to better interact with their students on varied levels and gain insight on their students' methods and styles of learning.

Recommendations

Future research directives initiated as a result of this study should incorporate qualitative data to obtain a more detailed explanation and rationale behind science teacher efficacy beliefs as they pertain to minority success in environmental and general science. Future research directives should also assess efficacy of teachers exposed to both high minority and nonminority CED; efficacy levels could then be assessed for each treatment and compared with trace, and/or confirm any deficit in efficacy based on CED. Lastly, teacher efficacy should be further examined: does it change over time? Does it change with years of teaching experience? Is teacher efficacy different in mixed race schools or majority minority schools when compared with that of nonminority schools?

A limitation of this study was the difficulty in obtaining a causal conclusion from cross-sectional data. A causal–comparative analysis cannot pinpoint a definitive causal link between science teacher efficacy and the achievement of minorities in environmental and general science. There are numerous variables other than science teacher efficacy that may impede minority success in science. These include students' own self-efficacy, socioeconomic factors, nonattainable academic resources, and familial structure (Bandura, 1986; Pajares, 1996). However, low science teacher efficacy has been shown to substantially lower student outcomes and achievement levels (Ashton & Webb, 1986; Hoy, 2000; King et al., 2001).

To maintain equality in science curricula, educators must refuse to alter curricular goals because of students' behavior, ethnicity, socioeconomic status, and/or perceived intellectual abilities. The consistently low efficacy scores in this study for science teachers with high minority CED are a critical point of concern and warrant further investigation.

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A Teacher's Journey with a New Generation Handheld: Decisions, Struggles, and Accomplishments

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In this technology-oriented age, teachers face daily decisions regarding the use of advanced digital technologies—graphing calculators, dynamic geometry software, blogs, wikis, podcasts and the like—to enhance student mathematical understanding in their classrooms. In this case study, the authors use the Technological, Pedagogical, and Content Knowledge (TPACK) model in conjunction with a five-stage developmental model, which can be used to describe growth in TPACK to describe the initial attempts of a teacher, Jane, to develop TPACK as she learns and attempts to integrate an advanced teaching technology into her classroom, namely the TI-Nspire graphing calculator. The study tracks her struggles to reconcile some traditional beliefs about how students learn with her desire to be responsive to what she perceives as affordances of advanced digital technologies. Main data collection methods were journal writing, observations, document analysis, and interviews. Using the five-stage developmental model, we saw that this experience helped Jane to move among different stages. This study showed that the TPACK model with the five-stage developmental model can be a beneficial tool for researchers to study teachers' professional growth and is also a valuable tool for teachers to reflect on their own growth.

> It is important for our students to learn both ways. As a teacher, I am a firm believer in having students perform tasks by hand simply so they can see the process by which a graph or table is constructed. I think doing things yourself is the best way to understand them. However, we live in a technological age and rarely in any situation would my students be required to construct a table, graph . . . what kind of teacher would I be if I didn't expose them to the enrichment technology has to offer them?

The National Council of Teachers of Mathematics (NCTM, 2000) states that "effective use of technology in the mathematics classroom depends on the teacher . . . The teacher plays several important roles in a technology-rich classroom, making decisions that affect students' learning in important ways" (pp. 25–26). In the quote above, Jane (a pseudonym) discusses one of her many decisions regarding the use of advanced digital technologies in her classroom. As she attempts to reconcile her belief in the importance of "doing things by hand" with her desire to engage students in technology-rich activities and improve her students' learning, she is caught in a dilemma common to many teachers.

A number of studies suggest that teachers' beliefs and views influence their practices in the classroom (Ball, Lubienski, & Mewborn, 2001; NCTM, 1991; Stipek, Givvin, Salmon, & MacGyvers, 2001; Thompson, 1984, 1992). Furthermore, teachers typically control whether or not advanced digital technologies—graphing calculators, dynamic geometry software, blogs, wikis, podcasts etc.—are among the instructional materials used to enhance student mathematical understanding. In their study, Doerr and Zangor (2000) concluded that the beliefs of teachers about the use of graphing calculators affected whether and how they used the tools in their classrooms and highlighted the teacher's role in transforming a computational task to an interpretive one. Teachers' beliefs about the roles of graphing calculators have also been associated with the use and role of calculators in mathematics classrooms (Burrill et al., 2002; Doerr &

Zangor, 1999; Kastberg & Leatham, 2005). For instance, teachers who believe that graphing calculators can be used for fostering inquiry use technology differently than colleagues who view the devices primarily as tools to perform fast computations, easing the burden of pencil-and-paper work.

Several studies have emphasized the importance of teachers' views regarding mathematics and the influence of these views on teachers' uses of technology during instruction (Burrill et al., 2002; Tharp, Fitzsimmons, & Ayers, 1997). Tharp et al. (1997) concluded that a relationship exists between the rule-based view of mathematics as manipulation of symbols and memorization of facts and the view of graphing calculators as not enhancing mathematics instruction. On the other hand, teachers holding non-rules based view of mathematics as reasoning about relationships and patterns believed that the graphing calculators should be integrated in mathematics instruction. Other studies have emphasized the relationship between teachers' pedagogical views and the use of calculators and have conclude that teachers who favor discovery and inquiry methods tend to make more instructional use of graphing calculators (Penglase & Arnold, 1996).

Teachers are faced with a complex decision-making process of how to deploy their content knowledge, technological knowledge, and Pedagogical Content Knowledge (PCK; Shulman, 1986) to best serve student learning. Advanced digital technologies add an extra dimension of complication and require the deployment of Technological Pedagogical and Content Knowledge (TPACK; Mishra & Koehler, 2006).

Research Question

Our work in this study is guided by one central question, namely *How does a teacher integrate an advanced technology into her instruction?* To address this question, we tracked and observed Jane's decision-making processes and TPACK development through journal writing, observations, and interviews as she took initial steps to integrate the TI-Nspire into her instruction. The study tracks her struggles to reconcile some traditional beliefs about how students learn with her desire to be responsive to what she perceives as affordances of advanced digital technologies.

Theoretical Framework

The TPACK model provides the main theoretical framework for this study. Shulman (1986) first discussed teachers' knowledge as a complex structure, introducing PCK as the intersection of content and pedagogical knowledge. Twenty years later, Mishra and Koehler (2006), Koehler and Mishra (2005), and Niess (2005, 2006, 2007) expanded Shulman's work to include technological understanding, presenting the education field with the TPACK model (see Figure 1). While Mishra and Koehler discuss the interplay of content and pedagogy from a decidedly instructional technology perspective, Niess focuses more attention on mathematics teachers and their TPACK.

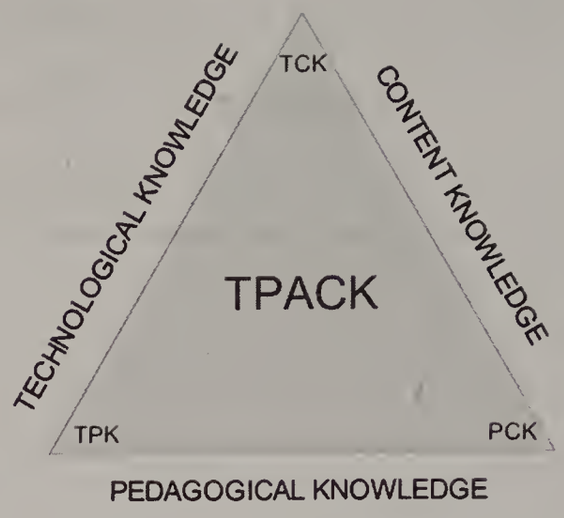


Figure 1. Recreation of Mishra and Koehler's TPACK model.

The TPACK model adds another component, technology knowledge, to Shulman's structure. With TPACK, we have a more complex model with three types of knowledge—technological knowledge, content knowledge, and pedagogical knowledge—represented as sides of a triangle, as shown in Figure 1. When technology is considered along with pedagogical and content knowledge (PCK), more combinations of knowledge must be considered in addition to PCK. For instance, the model encourages educators to explore Technological Content Knowledge (TCK) and Technological Pedagogical Knowledge (TPK). These combinations are represented as vertices of the triangle in Figure 1. PCK focuses on issues such as teacher selection of instructional methods based on their content knowledge and their knowledge of various pedagogical methods. When discussing TCK, Mishra and Koehler (2006) noted "teachers need to know not just the subject matter they teach but also the manner in which the subject matter can be changed by the application of technology" (p.1028). On the other hand, they note

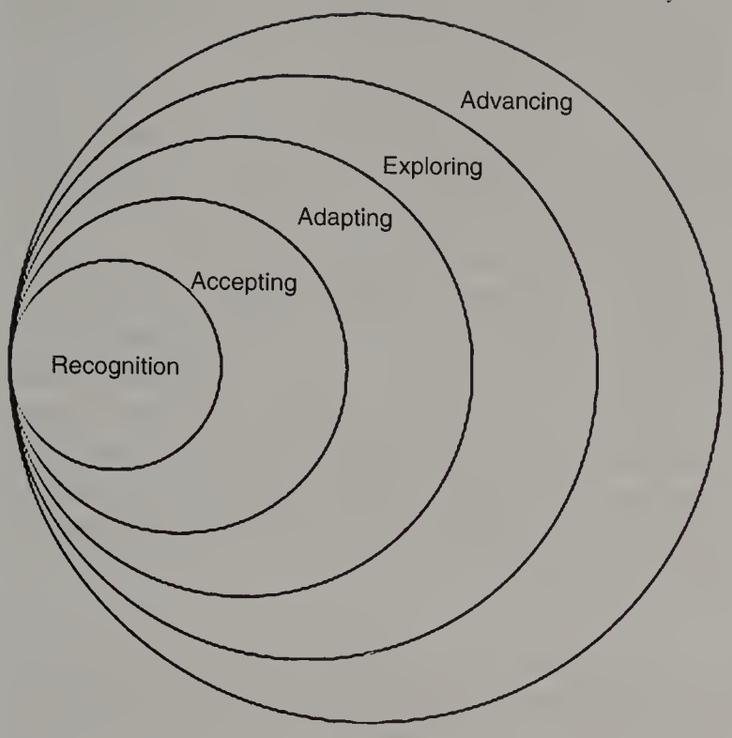


Figure 2. Five-stage developmental model (Niess et al., 2007; The visual structure of this figure is inspired by the Pirie and Kieren [1994] model).

that "technological pedagogical knowledge (TPK) is knowledge of the existence, components, and capabilities of various technologies as they are used in teaching and learning settings, and conversely, knowing how teaching might change as the result of using particular technologies" (Mishra & Koehler, p. 1028). TPACK is at the center of this model, requiring educators to consider all knowledge types and combinations as a whole.

The next module of the framework focuses on how teachers might develop their TPACK. Niess, Sadri, and Lee (2007) and Niess et al. (2009) described a five-stage developmental model of TPACK (see Figure 2). The idea has its origins with Rogers' (1995) innovation-decision process model. Rogers argues "individual's decision about an innovation is not instantaneous act. Rather it is a process that occurs over time" (p. 162). Through a longitudinal study, Niess et al. (2007) adapted and developed Rogers' five-stage sequential process in terms of mathematics teachers integrating spreadsheets technology into their teaching to discuss teachers' TPACK development. We describe each stage of the model in more detail in the following paragraphs.

At the **recognition stage**, teachers consider technology as one of many tools for teaching and learning content. At the **accepting stage**, the teacher needs to decide whether he or she will use the technology during instruction. At the next stage, **adapting**, the teacher begins to experiment with technology outside the classroom, adapting experiences with the technology—perhaps creating worksheets or other materials with technology but not yet engaging students with the tools directly. At the **exploring stage**, the teacher actively investigates his or her curriculum in an effort to incorporate new technology-oriented ideas for teaching and learning *with students*. At the final stage, **advancing**, the teacher reflects on the results of the integration of technology in instruction and advances the curriculum, integrating the technology appropriately as teaching and learning tool (Niess et al., 2007; Niess et al., 2009). In 2009, the Association of Mathematics Teacher Educators (AMTE, 2009) adopted and published the *Mathematics TPACK (Technological Pedagogical Content Knowledge) Framework* at their website. Niess et al. (2009) proposed a very detailed mathematics teacher TPACK development model describing the development of TPACK toward meeting the standards similar to the Mathematics TPACK Framework. This model was based on the Rogers and Niess et al. (2007) models. Hence, we used the combination of these two modules (TPACK model and five-stage developmental model) for the framework of this study. While the five-stage developmental model helped us to see Jane's progress in general, the TPACK model helped us to see the growth of her TPACK and the part(s) of TPACK was (were) involved during specific encounters. Without being hierarchical, the development model is a "movement" model as the teacher moves on the scale and sometimes reverts to earlier stages and sometimes moves forward. We see the TPACK model as more of "fill-in" model with accretion of experiences or directed professional development allowing a teacher to address different domains of the triangle and "add more" to their skill and sophistication toward each vertex. Examining a teacher's development along the dimensions of both models allows researchers to see how trajectories of growth examined in the developmental model result in a more "filled-in" and therefore more sophisticated TPACK.

Data Collection and Analysis Methods

For this study, data collection methods included journal writing, classroom observation, document

analysis, and interviews. Jane first experienced the TI-Nspire calculator as she worked on a set of self-paced introductory activities developed explicitly for teachers. Later, she used TI-Nspire in her teaching, and she responded to general and specific writing prompts designed to provide a better understanding of her attitudes and beliefs regarding the calculator. At the beginning of the study, Jane reflected on her general beliefs regarding the use of technology through entries in a teaching journal. After she started using the technology in her classroom, Jane described specific classroom episodes and planning experiences with TI-Nspire in her journal. During the data collection period, Jane responded to the following prompts:

- What kind of *technology* skills that you can use later in your profession are you learning? Describe how you intend to use those skills in your future teaching.
- I have been thinking and working a lot on the *pedagogy* of the activities I am designing. Yes__ No__ Because _____
- *Pedagogical* issues related to the activities I am designing are _____
- I have been thinking and working a lot on the *technology* of the activities I am designing. Yes__ No__ Because _____
- *Technological* issues related to the activities I am designing are _____
- I have been thinking and working a lot on the *content* of the activities I am designing. Yes__ No__ Because _____
- *Content*-related issues related to the activities I am designing are _____
- Consider the relationship between the activity *content* and *pedagogy* and discuss how the activity content and pedagogy influence one another (when technology is used).
- Consider the relationship between the *pedagogy* and *technology* and discuss how the activity pedagogy and technology influence one another.
- Consider the relationship between the activity *content* and *technology* and discuss how the technology and the activity content influence one another.

The wording of some of the prompts is based on the survey questions in Koehler and Mishra (2005). At the end of the study, in an unstructured response format, Jane reflected back on her experiences and wrote about her perceptions of how the use of the TI-Nspire calculators helped or hindered her teaching and her students' learning.

On two occasions, Jane and her students were observed as they used the calculators to study concepts of slope and line of best fit. Jane created lesson plans specifically designed for use with the TI-Nspire. These were collected for document analysis. At the end, one of the authors interviewed Jane to determine her general reflections of the entire experience. The interview was facilitated in a semi-structured format following a format that paralleled earlier writing prompts. The format allowed the interviewer to gain additional information regarding specific entries in Jane's journal and specific events noted in the classroom observations.

Data analysis started with Jane's journal entries, lesson plans that she created, and field notes of classroom observations with attention paid to the chronological order of the artifacts. At the first stage, the TPACK model was used to guide the coding and data interpretation processes. We focused specifically on the content-, pedagogical-, and technology-related codes. After anticipating these three major codes, other codes/subcodes and interactions among codes emerged. These included (1) first pencil and paper and then technology; (2) technology use to explore relationships; (3) the use of linkages among multiple representations with technology; and (4) technology as hindrance for learning. At last, the interviews were coded and analyzed. Some of the decision rules followed for data entry and selecting quotes included (1) the use of codes consisting in all four types of data in reporting the results; (2) consideration of rival/contradictory explanations, even though they were not mentioned in all types of data; and (3) selection of participant quotes when reflective and/or communicative. Because Jane's story is chronological in nature, "time-ordered display" was used (Miles & Huberman, 1994). According to Miles and Huberman, time-ordered display is "a second major family of descriptive displays [that] orders data by time and sequence, preserving the historical chorological flow and permitting a good look at what led to what, and when" (p.110). The five-stage developmental model guided this stage of analysis and was used to create an illustration of the data.

Data triangulation and member checks were used to ensure the trustworthiness of this study. The use of the teaching journal helped ensure that Jane had sufficient and private time to respond to prompts in an

environment of her choosing. On the other hand, the interview and classroom observations provided us with varied environments to observe Jane. Our document analysis (including lesson plans) was strengthened through the collection of other types of data, particularly classroom observation. Thus, the four forms of data collection—each with different encounter levels—provided rich sources of data for this study. Moreover, the synthesis of the TPACK model and the five-stage developmental model bolstered the data analysis as theory triangulation. Questions for member check during and after the interviews were used in order to ensure common understanding of what Jane's intended meanings as well as fidelity in the analysis.

Results

In this section, we intersperse Jane's voice (in a blocked text) with our interpretations guided by our theoretical framework. Specifically, we analyzed journal entries, interview responses, lesson plans, and observations along the spectrum of recognition, accepting, adapting, exploring, and advancing, as well as within the triangular framework of PCK, TCK, and TPK. We start with Jane's preexisting views about the use of technology in instruction then describe her initial experiences and planning with TI-Nspire. In the third subsection, we introduce the lesson plan that Jane created along with her decisions behind the development of this instructional material. The next section focuses on Jane's reflections on the lesson. Interactions among her knowledge types in TPACK during this whole experience are discussed in the last subsection.

The Use of Technology in Instruction

> Overall, I feel that graphing calculators play a fairly significant role in the understanding of several mathematics concepts, particularly in algebra. I have used the TI-83 and TI-84 family of calculators in my classroom since I began teaching four years ago, and the students really seem to enjoy seeing the graphs appear and how the graph is affected when the equation is changed. It has been a terrific asset when performing lessons on finding the roots of an equation or solving simultaneous equations. I have also used them (graphing calculators) extensively for lessons involving exponential functions, matrices and statistics. Of course my students prefer to graph on a calculator rather than by hand because the graphs are more precise and faster to create. I use the graphing functions quite a bit to illustrate a principle I am trying to communicate through equations. It is often easier for them to see when the graph appears and we talk about the different quadrants (Journal Entry, March 1, 2008).

This statement is a benchmark that typifies Jane's relationship to advanced digital technologies prior to her use of "next generation" calculators (namely, the TI-Nspire). Like many teachers, Jane has established a comfort level with the affordances of graphing technology. She uses the tools to ease of production and manipulation of graphs and, like many teachers, employs the graphing calculator as an alternative to algebraic manipulation when equation solving requires cumbersome calculations (e.g., using the quadratic formula to solve $x^2 - x - 1 = 0$) or when solutions are not accessible with by-hand techniques (e.g., solving transcendental functions such as $e^{(-x)} = x$ or $x = \sin(x)$). The power of graphical solution methods is suggested in Figure 3.

Without question, at the beginning of the study, Jane was operating at the *accepting* stage in terms of her use of graphing calculator technology. She had already recognized numerous positive influences of graphing calculators in her teaching—from enhancing student motivation to faster, more accurate production of calculations and drawings. At the same time, Jane initially had reservations regarding the use of calculators in introductory courses because of a perceived risk of "calculator dependency" among younger learners:

> Initially we do not like our freshmen to use the calculators at first. Just because we worry that they get a little too dependent on them not just as far as graphing would go but even like basic multiplication (Interview, April 28, 2008).

Prior to her use of TI-Nspire, Jane also thinks that technology should be preceded with by-hand skills:

> I still believe doing calculations by hand gives them [students] a better understanding of where the numbers are coming from and makes it easier for them to do more complex mathematics later on (Journal Entry, March 1, 2008).

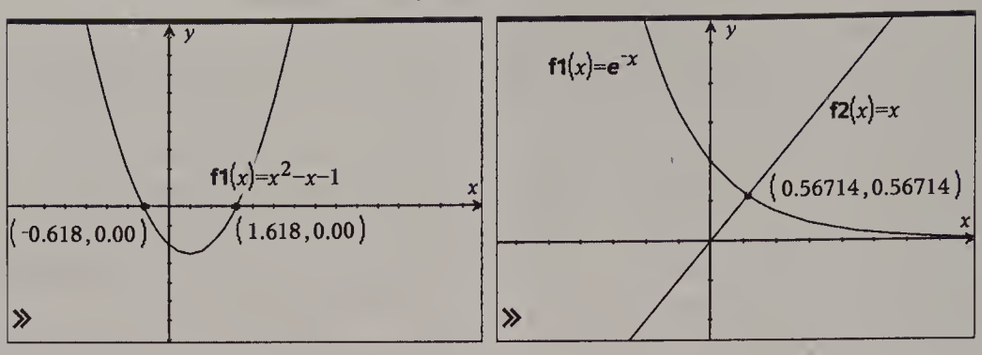


Figure 3. Graphical equation solving methods of the TI-Nspire enable students to calculate numerical solutions that otherwise require significant by-hand work (left) or are not solvable using traditional paper-and-pencil methods (right).

Here, Jane's reflection shows us that, to her, by-hand computation is the best means for fostering conceptual learning in her students; so she cannot let go of her traditional view of learning. According to this view, Jane's TPK falls somewhere between *recognition* and *accepting* levels. While Jane *knows* that technology offers students promising capabilities, she prefers to use technology after her students have learned how to do things by hand.

> I prefer it [first using paper and pencil] just because I feel like if they do not see where it came from then it is harder for them to grasp what is actually happening . . . I think it is harder to really conceptualize what is going on . . . when I have asked students even high level students just to graph things by hand. After having used the calculator, they can't. They will give me the scale all wrong . . . They will be just like copying this graph off of their calculator or I don't really feel like they are getting the idea that the graph has a meaning behind it unless they have that by hand kind of experience (Interview, April 28, 2008).

Jane states that she believes that when students study mathematics by hand first, they learn the concepts better. But at the same time, toward the end of the interview, she provides more procedural examples where students do things wrong after using the calculator (e.g., forgetting to label axes, constructing incorrect scales with graphs).

At this stage, Jane accepts technology, although perhaps reluctantly. She states several times in several ways some version of the view that technology is suitable to be used but only if you "know the mathematics" first. However, as witnessed in the passages that follow, as Jane begins to implement a new technology in her class—the TI-Nspire calculator—she moves along the TPACK steps, almost reaching the level of exploring.

Initial Experiences and Planning with TI-Nspire

> At first, to be honest, I was a little bit frustrated and I had a hard time grabbing the line and having it do what I want it to do. I really liked the idea that it could do all this stuff. But when I first started using it, it was a little bit difficult for me . . . But I mean that I think it is that way with any technology that you use. I have to say that you know first time I used regular Excel software or whatever starting to getting used to, making spreadsheets, and putting in formulas and implementing everything, it was a frustrating experience. But now I use it all the time (Interview, April 28, 2008).

Through our observations of Jane, both as a student in one of the author's graduate courses and as the subject of this study, it quickly became clear that she is very "technology savvy" person. As the preceding interview segment suggests, Jane is a persistent technology user. Adverse experiences with the TI-Nspire motivated Jane to learn more about the new calculator. Such behavior illustrates the technology aspect of TPACK model; Jane is potentially willing to *explore* more about new technologies and perhaps *adapt* her lesson to include new technologies in order to help her students learn mathematics more effectively. Jane recognized that the new technology offered much to her students and to the teaching and learning environment.

> From playing around with the TI-Nspire calculators, I am learning how to use a new and much

> more sophisticated calculator than I am used to using in my classroom . . . So far I have only played with the attributes applying to graphing lines and entering data although it is obvious I could do so much more given the time . . . I really like that it had the ability to do the line manipulation. I thought that there was a really unique feature that kids would not see otherwise. I mean it would take them forever to sit there and try to push a number and okay let's see if I change the slope a little bit what is does and then re-graphed it. (Journal Entry, March 5, 2008 and Interview, April 28, 2008).

Although Jane stated that she was not thinking specifically of the technological aspects of the lesson she was designing, she was planning to use the TI-Nspire in her lesson. On the other hand, Jane mentioned that she was really focused on the pedagogy and content.

> I want my students to come away from this experience having both used new technology in their learning and having an enhanced learning experience . . . I realize that some students will be very proficient at using the calculators and will be able to see the big picture of what I am trying to accomplish here, while others will lag behind. This difference will cause issues regarding how to keep everyone in the same place without the more advanced students becoming bored or disruptive. My other main concern from a teaching standpoint is my own lack of experience in using these calculators and being able to help my students when a problem arises (Journal Entry, March 5, 2008).

Jane is transferring her anxiety about using a new technology to her students, but we see her advancing to the adapting stage in planning the content of her lesson. Aware as she is that the power of the technology lies in performing computations, she is determined to focus more on conceptual issues in her lesson.

> My biggest fear in designing these worksheets is that the students will simply follow the steps of entering things on the calculator, but not really see the relationship among equations, graphs and tables. For this reason, I have chosen not to use the templates designed by TI, but taken their ideas and modified them in a way I think my students will understand and be forced to answer questions regarding the relationships among these three things (Journal Entry, March 5, 2008).

This is an important step for Jane as she starts to view the TI-Nspire calculator as a tool to explore relationships and concepts rather than a hindrance to developing deep understanding.

> I did not really feel that the lessons that I first looked at were going to take them as step by step as I needed to and asked the critical questions in between that I felt it would lead to their understanding. I thought that the questions asked in the lessons provided by TI were good for getting them used to the capabilities of the calculator, but did not ask very probing questions about the concepts behind what the students were learning. I really wanted them to be able to explain what happened each time they changed their equation and why this change made sense (Interview, April 28, 2008).

We see here that Jane has sufficient sense of what she wants. She does not simply mimic the activity that she located; rather, she adapted and developed it according to her students' needs where students engage in an exploration task. This shows that she is taking a step from *adapting* to *exploring* stage.

The Lesson Plan

> For this particular study, most of what I used was the graphing capabilities, and using the lists and the scatter plots. I opted not to have my students use the least squares regression line, just because I wanted to them to try and find the best-fit line by manipulating it. But I mean I probably would use that in the future as we had a little bit more time getting to it. And I used the table feature and putting in your own data in the table and transferring that (Interview, April 28, 2008).

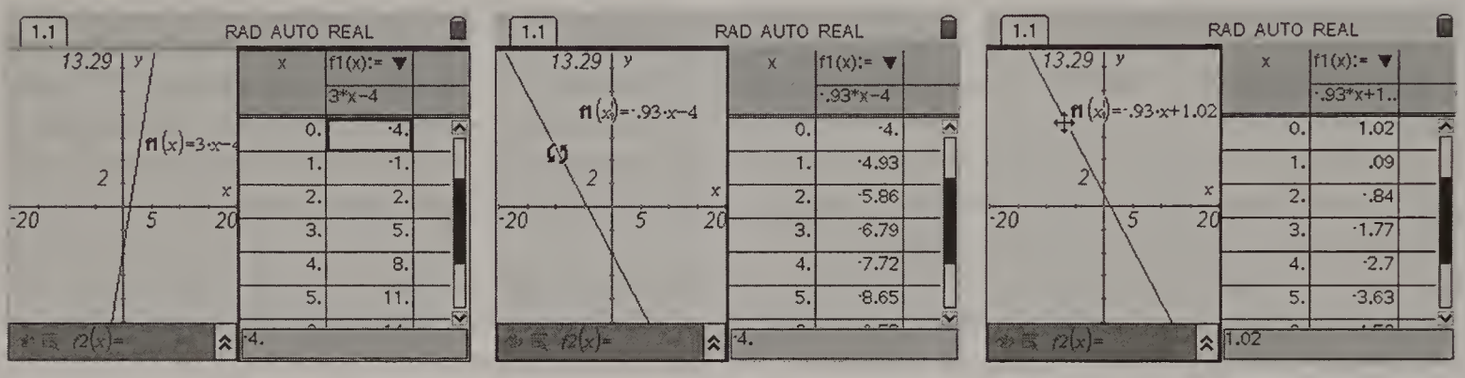
Jane developed three main activities over four school days. First activities were focused more on the graph and the algebraic form (see Figure 4) with an aim of "getting students used to using all the [technological] stuffs. I mean I wanted them to be able to use the calculator and practice the manipulating the line before I gave them a true application" (Interview, April 28, 2008).

Graphing and Manipulating a Line

1. Turn your calculator on and press the key.
2. Use the arrows to select graphs and geometry and then press the center button or the enter button.
3. At the f(x) prompt, put in x+3 and press enter.
4. Press the tab button to get into the graph.
5. Here's the fun part.
   a. Move the cursor around using the arrow keys. (you can use it almost like a mouse pad)
   b. Play around with it until you see either a hand or two little arrows in a circle. The hand allows you to move your line up or down and the arrow key allows you to rotate your line.
6. Now that you have moved it around a little bit, write down the new equation of your line.

   _____
7. See if you can manipulate your line to do the following and write down the corresponding equations you are getting.
   a. Double the slope you have written in # 6. _____
   b. Make your slope negative from that of # 6. _____
   c. Double your y-intercept. _____
   d. Change the sign of your y-intercept. _____

Figure 4. Part of the activity focuses on the relationship between the equation and the graph.



(a) (b) (c)

Figure 5. Manipulating the line in a multi-representational environment.

Other parts of the lesson included activities such as graphing $y = 3x - 4$ and splitting the screen (see Figure 5a) and creating a table, changing the slope on the table side, and observing the changes in the graph. Next, students would search for y-intercept in the table and compare the y-intercept with the equation. Finally, students would manipulate, rotate (see Figure 5b), and move (see Figure 5c) the graph of the line and discuss how the values in the equation and the table changed. When asked if the main aim of this activity was to increase students' technological knowledge or content knowledge, Jane responded in the following manner.

> Well I guess kind of both. I mean that they needed to be familiar enough with the technology to be able to perform the functions that they wanted it to do, number one. And content wise I think they needed to make that connection between like when I changed the equation, my graph does this . . . I had them do a lot with where they were playing with their slope and they describing what happened to the line and context when they their slope in such a way. I think that helped them a lot to be able to interpret what was going on when it finally came to the real-world application of it (Interview, April 28, 2008).

Jane planned to use the application part of the activity on the second day. Figure 6 displays a part of the worksheet showing the level of detail provided for students along with the context of the activity.

The remainder of the activity encouraged students to create plot graphs, then enter and drag a function graph (e.g., $y = .1\,x$) to estimate the line of best fit. After performing these tasks, Jane's teaching materials asked students to answer a series of questions related to lines of best fit. Several prompts are provided below:

Most Important: Pressing Control then Escape will undo any Action.

Entering and Graphing Data

1. Turn your calculator on and press the key.
2. Use the arrows to select lists and spreadsheets and then press the center button or the enter button.
3. We would like to know if there is a relationship between how fast you drive and how much fuel is used.
   a. Using the navigation pad, (the circle with the arrows on it), highlight the little space next to the A in column A. Type in speed.
   b. Again using the navigation pad, highlight the space next to the B in column B and type in fuel.
   c. Insert the following data into lists A and B

Speed (km/h)	Fuel Used (liters/100 km)
70	6.3
80	7
90	7.6
100	8.3
110	9
120	9.9
130	10.8
140	11.8

Figure 6. Real-world application part of the lesson.

- A best-fit line normally has an equal number of points above and below the line, does yours appear to meet this requirement?
- Did you rotate your line at all or just move it up and down? What impact does rotating (moving the line up or down) the line have on your equation?
- Based on your new equation, what would you say would be the fuel used if you were driving at 150 km/h?
- The actual fuel consumed would be 12.83 L/ 100 km, were you very far off?

Until now, the lesson was written as a whole-class activity. However, the third part of the lesson asked students to complete worksheet items at their own pace answering algebraic and graphical (Figure 7a) and contextual questions (Figure 7b) using TI-Nspire.

When Jane was working with *TI* created materials, she decided not to use the premade worksheets. Instead, she created her own according to what she wanted her students to accomplish. As she utilized the new capabilities of the novel technology, she considered pedagogy (even though she wrote mainly about classroom management) and content together to reflect on how her questions might help her students to think about the concept of lines of best fit. Her questions regarding the relationships among table, equation and graph, and her contextual questions focused mainly on the concepts of slope and *y*-intercept in a discovery nature. Jane's TCK and TPK played important roles in this decision-making process. Her lessons focus more on the concepts of slope and *y*-intercept while de-emphasizing procedural tasks such as how to locate slope and *y*-intercept in a graph/equation or scaling or labeling of the graphs. Moreover, Jane considered that her instruction would use a novel capability of this new technology—namely the manipulation of graphs with dynamic updating of algebraic forms—that she cannot provide using other means. The lesson represented a new way for her students to learn about multiple representations of function, slope, and intercepts. As such, Jane carefully considered how to introduce the technology to help her students follow steps that she specifically created for them. These behaviors suggest that Jane is possibly moving from *adapting* to *exploring* stage.

3.) Graph the following function on your calculator: $f(x) = x + 5$

a. Manually alter your graph so that the slope increases by at least 4; write the equation of your new line: _____

i. What does your new line look like in comparison to the original?

b. Manually alter your graph so that the slope becomes very small, but still positive; write the equation of your new line: _____

i. What does your new line look like in comparison to the original?

c. Manually alter your graph so that the slope becomes negative; write the equation of your new line: _____

i. What does your new line look like in comparison to the original?

d. What affect does changing the slope have on a given function?

(a)

5.) You and your friends have decided to sell bagels in the morning before school. You are projecting this to be very successful and plan to buy 300 bagels at $0.40 each. You plan to sell the bagels for $0.75 each and your equation is: $p(x) = 0.75x - 120$.

a. Enter this equation into your calculator.

b. Using the table from your calculator, determine how much you would have to sell (x) in order to make a profit. (Hint: Profit means you are making positive, not negative, values.)

c. From the graph of this equation, at approximately what x – value do you make your first profit?

d. How are your answers to parts b and c related? Why?

(b)

Figure 7. Last day activity.

Teacher Reflections after the Lesson

> The first day with our calculators did not go as smoothly as I would have liked. For some reason, I couldn't get the overhead calculator to work . . . They [students] seemed to think the calculators were pretty cool and liked graphing on them. It was difficult without the projector to show them what I wanted them to do and my verbal instructions along with the handout I provided were not enough for some students . . . We didn't accomplish near [sic] as much as I had hoped, but I think that is more the fault of my own personal unfamiliarity with the technology rather than a problem with the calculators themselves (Journal Entry, March 10, 2008).

Jane's nightmare came true, and her lack of experience caused a classroom management issue. So Jane's first struggle involved technology usability issues rather than pedagogy or content concerns. She solved that problem and next day everything worked well.

> The lesson today went pretty well. We finished up the lesson from yesterday together, and the students were able to see how the graphs, equations and tables are related together all on the same screen. They seemed to really like being able to see the graphs and table together. I liked watching their reactions as the graph jumped when I told them to change the slope of the equation in the table. I think it was also very good for them to see how the values in the table changed as we manipulated the line by moving it up and down or by rotating it about its *y*-intercept. We accomplished this by writing down several values from the table on the board and then comparing them to the new values displayed in the table as we altered the graph. This was probably the best part today, as my main goal in bringing in the calculators is for my students to see how the graph, table and equation all represent one entity. I think they could really see this here (Journal Entry, March 11, 2008).

We notice here that Jane is not expressing concern about understanding underlying concepts because they neither performed the calculations by hand nor drew the graphs themselves. In fact, she is focused on how the affordances of the technology coupled with her questions helped students see and make meaning of the underlying concepts. She utilized the technology to create an experience for her students that she could not replicate otherwise. She also acknowledged that many of her students seemed more motivated with the inclusion of TI-Nspire technology in the lesson. As a result of these experiences, in order to create better learning environment for her students, Jane realized that she needed to change some aspects of the lesson. Interestingly, Jane started with her own role as a facilitator in the teaching and learning process.

> The most important for me . . . first I would like say it is the learning of the students. But most important for me was learning how to vary my instruction in order to enhance the learning of the students by using that technology. Because I felt like I had to really change my role as a teacher in order to let them discover what was going on. Because they are so quick to say that "I don't get" "I need help." And I am so quick just to run over and help them and I have to kind of learn to step back and say "why do not you just try this?" or "What you think about that?" rather than trying to give them the answer. I have to be more careful about guiding them and facilitating their learning. Rather than just making a more rote type of learning. And that was a difficult transition for me. [When asked about what was the role of technology in this transition, she said that] Well, the role of technology was that the students spent more time finding out about the relationships of graphs, equations and tables from the graphs they created on their calculators than from the ones I showed them on the board (Interview, April 28, 2008).

Now Jane is developing and reflecting on her TPK. She structured her instruction with technology for optimum learning. She clearly views the technology as a tool that can help her to have a more student-centered instruction. However, this transition is not easy for her when she does not have the full support from colleagues in her school.

> Because I am a traditional more so type of teacher. It is usually the way my school is. So I am kind of one of the few who has been stepping away from that a little bit. So far my department I mean it is not that is unwelcome. When I try to get people to do it, they are just like "you do your thing" (Interview, April 28, 2008).

The rest of the second day, Jane's students started working on the application part of the activity, which she downloaded from Texas Instruments Web site and adapted for her needs and the needs of her students.

> I really wanted the students to experience what a regression line is, so in my activity I have them graph some data relating to speed and fuel consumption and then put in a line that doesn't quite go through any of the points. My goal here is for the students to use the skills they have gained yesterday manipulating the line to move this line into the best possible position of a regression line from a visual perspective. My motivation here is

twofold. I would like the students to further practice the acts of moving the line around on the graph to increase their skill level in that area, and I would also like the students to visually try to establish what a best fit (regression) line should be for this data. I think that by having the students find the line, rather than the calculator giving it to them will help them understand where the line comes from and how it is used (Journal Entry, March 11, 2008).

Again, here we can observe that Jane *explores* how she can use the novel capabilities of the technology to introduce a concept that she could not do before with older technologies. On the third day of using TI-Nspire, her students discussed best-fit lines and how to determine what constitutes a "good fit" and a "better fit." One student commented that this experience was frustrating. She could not move the line as she wanted. A couple of students experienced the same difficulty. One student could not move the line side to side because she was in the twisting mode. Many experienced difficulties when attempting to answer a question asking them to enter a specific x value to their model to estimate fuel consumption.

> The students are progressing well with the calculator use, although I'm not sure if it is truly helping them understand functions better as I had hoped it would. One of the questions on the activity relating to the best fit line was for the students to use the equation of their line to predict fuel consumption at a speed of 150 km/h and several of them said they did not know how to do that. This shows that although they can go through the steps of attaining a best fit line, I am obviously not communicating to them the purpose of this line and how it pertains to any real outcome. That is really disappointing (Journal Entry, March 12, 2008).

At this point, Jane's struggle is more pedagogically grounded. During the interview, Jane stated that "maybe we needed to have more group discussions at that point." She reflected that the problem, in this case, centered on application questions, those in which students had to interpret the information that they gathered from their calculators. She concluded that different types of questions, different sequencing of tasks, or whole/group discussion might have helped students resolve their difficulties together as a class. On the other hand, she observed that her students were able to deal with slope and y-intercept concepts and connecting three representations together but not the concept of function in a general sense and specifically best-fit line concept as she hoped.

> I really think that the TI-Nspire calculators helped in teaching my students the effects slope and y-intercept can have on the equation of a line. I also think it helped my students to see the relationship among graphs, equations, and the tables associated with these equations. They seemed to enjoy seeing how the table values would change when they altered the graph or the equation in class . . . I am really not sure if the experience has helped them understand the purpose of a function or how a function worked. They seemed more focused on learning how to use the calculators and what was happening to the graphs than on what it all actually meant. I say this because many of them had trouble answering the questions asked in the final steps of each project . . . This also showed that although they knew the table and graph influenced each other, they had little understanding of what this meant in the context of the given problem (Journal Entry, March 14, 2008).

As Jane attempts to keep the focus on technological and pedagogical concerns, she is provided with an opportunity to further develop her TPK. At the end, Jane thought that

> [T]he use of these calculators was beneficial to myself and my students . . . I do think it helped them see the relationships I had set out to show although the term function is still somewhat elusive to many of my students . . . Most teachers also feel the need to show students how to perform such activities by hand as well as on the calculator and accomplishing this takes time that not everyone can afford to spare. I do feel it is important for students to use them though. It is not too often that in their future jobs they will be required to perform complex algorithms by hand in the technology age we live in (Journal Entries, March 14, 2008 and March 25, 2008).

We hear something of a movement away from Jane's initial concern about students having to do everything

by hand first. She reflected that her classroom management and/or planning for instruction also changed during this process of transition but it was worth it.

> From an instructional perspective, our role as a teacher changes from leader to facilitator when technology is introduced in our classroom . . . I noticed myself that I would spend around ten minutes at the beginning of class going over how to perform manipulations on the calculator to get to the various screens they would need and maybe a few minutes at the end discussing the purpose of the lesson, but the rest of the time was spent answering questions one-on-one with students . . . using technology also requires a great deal of time commitment from the instructor. The plans need to be very explicit in order to draw out the desired conclusions from the students as they perform the task at hand . . . however, this role change from head of the class to facilitator of exploration is a more rewarding one. The students overall seem to get much more out of the experience (Action Research Project).

The Interactions Among Different Knowledge Types in TPACK

When Jane was asked to reflect on the interaction among different types of knowledge and those combinations in TPACK model, she commented that she could easily see how content influences pedagogy:

> I would say the content is really what is going to influence pedagogy more than the other way around . . . I mean you have to decide on a certain content that you were trying to get across to your students and then what strategy to use to present for those students and how you are going to draw that out of them, how you are going to make them real... what you are trying to accomplish there. (Journal Entry, March 12, 2008 and Interview, April 28, 2008).

Jane also noted that she could think about a mutual relationship between pedagogy and technology.

> Pedagogy and technology impact each other in both directions. The technology influences the method of teaching by allowing students to see results much more quickly and being able to discuss different results as I did not limit my students in how they moved their lines around . . . The pedagogy influences whether or not you are going to use it [technology] and how much you are going to use it . . . Well you are deciding how much time can be allotted for a given unit and how much of that time will be spent using a technological enhancement to the lesson and how much will be taught having them perform the algorithms by hand (Journal Entry, March 12, 2008 and Interview, April 28, 2008).

Finally when it came to the relationship between the content and the technology, Jane again was able to connect them mutually.

> You have to decide on what content you want to use. And then you can decide which technologies will be most appropriate to present that content . . . I used to be fairly a graphing calculator type of teacher. About now I am starting to get more into the idea of spreadsheets, Excel, and bringing in different ideas. Because you know they are going to use all those different things. They should have that experience, I think. . . . Vice versa, the technology influences the amount of different activities I can expose my students to by cutting down on the amount of time it takes them to see each scenario . . . We are no longer limited to supplying data that would graph perfectly. We can now show them real data with complex linear relationships (Interview, April 28, 2008, Journal Entry, March 12, 2008, and Action Research Project).

These show that Jane could take many parts (different types of knowledge and their combinations) of the TPACK model into consideration when reflecting on her teaching and her students' learning.

Discussion

Thinking back to the five-stage developmental model, we saw that Jane's experience implementing advanced technology in her teaching helped her move among different stages (see Figure 8). Jane's view of "doing things by hand first and then there will be room for technology" may have limited her use of technology in her instruction previously. Therefore, she was between recognition and accepting stages at the beginning of the study. As Jane considers the use of technology in this way, she is considering the TPK section

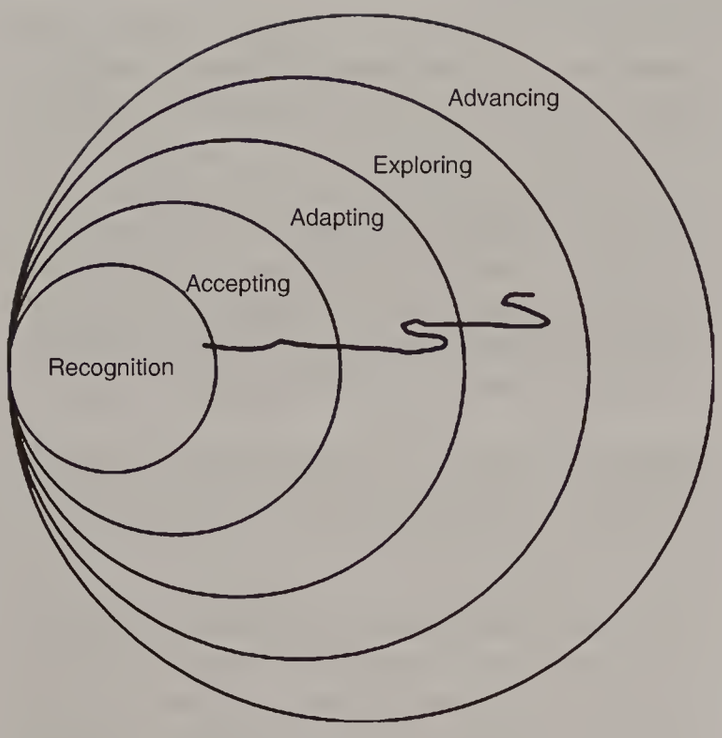


Figure 8. Jane's journey.

(vertex) of her TPACK—thinking that she would use technology after students mastered skills for optimum learning. After Jane started to learn more about TI-Nspire, we see her moving toward the adapting and exploring stages. At this juncture she is therefore "filling in" her TPK, making her total TPACK richer at this particular domain of the model. When she was developing her lesson, she made conscious decisions about her students' needs, and she adapted the activity for her classroom and instruction. As a result, Jane saw the benefits of using this technology on her students' learning, and her TPK "filled in" with the exploring level to engage "students in high-level thinking activities (such as project-based and problem solving and decision making activities) for learning mathematics using the technology as a learning tool" (Niess et al., 2009, p. 23).

Jane experienced some struggles during this journey. Her first minor struggle happened when she was developing her lesson. Her choice of questions or decision about whether to provide technical steps made her wonder if the worksheet would be a list of button-pushing versus an opportunity for her students to develop new knowledge. Here, again Jane's TPK domain was being addressed as she was adapting the activity according to the needs of her students and as she was bringing conceptual questions to the forefront of students' learning. Other struggles happened when Jane experienced technical difficulties or when her students were not able to answer some of the questions that she thought they would be able to answer. These drawbacks were highlighted in Figure 8 as folded parts. Her inexperience with the technology (i.e., lack of technological knowledge of her TPACK) influenced one of these struggles, and she was discouraged and blamed herself in her journal. However, Jane also achieved accomplishments such as being able to create an environment for her students to experience mathematics otherwise impossible and moved forward toward the exploring stage. Now she admitted that she is transitioning to become a facilitator in the class with the help of technology where she would not direct the most of the class.

We do not see this developmental process as a purely hierarchical one. As Jane moves forward in developing her TPACK (i.e., fills and sophisticates domains), she may encounter negative experiences that precipitate backward steps in the model. For instance, during the adaptation stage, a teacher can "begin to explore, experiment and practice integrating technologies as mathematics learning tools" (Niess et al., 2009, p. 21). If the outcomes of that exploration was not what he or she hoped for, or his or her students were more caught up with the technology itself, he or she might go back to the accepting stage where he or she "has concerns about students' attention being diverted from learning of appropriate mathematics to a focus on the technology in the activities" (Niess et al., 2009, p. 21). Jane progressed through the steps of the five-stage developmental model in a fairly linear fashion in this specific experience, but her TCK did not come into play that much during this specific experience and this domain does not fill or develop to a great extent. Her development and standings will likely differ for different mathematical topics based on her experiences with the technology, and her "paper-and-pencil first" belief will likely resurface. However, this does not mean that her professional development or the quality of her use of technology in her instruction will be affected negatively. As long as she continues to experiment with technologies with students in her classroom, we believe that she will continue to grow professionally while proceeding toward the advancing stage.

Without the support from her administration or fellow teachers, this transition is unlikely to be a smooth one. It was a good indication that her administration acknowledged her study and asked her

opinion about whether to purchase this technology. Now, Jane and her mathematics department are considering buying this technology. However, as Jane highlighted, without training, this technology could not be used to its fullest. This study showed that the TPACK model in conjunction with the five-stage developmental model is beneficial tool for researchers not only as a mechanism for tracking the deepening sophistication of a teacher's TPACK and to study teacher's professional growth but also as a valuable tool to be used in order to help teachers to reflect their own growth. A professional development opportunity where Jane or any teacher can reflect on each aspect of TPACK along with where they stand according to the five-stage developmental model could be very beneficial. When planning for optimum learning with technology, not only do teachers need technological knowledge but they also need to reflect on how these technological capabilities might help their students' learning. For instance, Jane reflected deeply on what type of questions might help their students' learning when they were using technology to do drawings and computations. Moreover, if teachers are informed about the TPACK and the five-stage developmental model, they might reflect better on their own development. This case study involved only one teacher over a short period of time and is limited to her work on a particular topic in the curriculum. More research with different teachers at different levels teaching different mathematical concepts with technology could inform better the mathematics teacher education literature about how these models might work in the field.

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Content Knowledge, Attitudes, and Self-Efficacy in the Mathematics New York City Teaching Fellows (NYCTF) Program

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The purpose of this study was to understand the mathematical content knowledge new teachers have both before and after taking a mathematics methods course in the NYCTF program. Further, the purpose was to understand the attitudes toward mathematics and concepts of self-efficacy that Teaching Fellows had over the course of the semester. The sample included 42 new Teaching Fellows who were given a mathematics content test, attitudes toward mathematics questionnaire, and teaching self-efficacy questionnaire at the beginning and end of the semester. Further, the teachers kept teaching and learning journals. Findings revealed a significant increase in both mathematical content knowledge and positive attitudes toward mathematics. Additionally, Teaching Fellows were found to have positive attitudes and high self-efficacy at the end of the semester, and relationships were found between attitudes and self-efficacy. Finally, Teaching Fellows generally found that classroom management was the biggest issue in their teaching, and that problem solving and numeracy were the most important topics addressed in their learning. Future studies should address self-efficacy differences between preservice and in-service teachers and the effects of alternative certification teacher knowledge, attitudes toward mathematics, and self-efficacy on students in the classroom.

Content knowledge, attitudes toward mathematics, and self-efficacy have become increasingly important issues in mathematics education (Amato, 2004; Ball, Hill, & Bass, 2005; Swars, Hart, Smith, Smith, & Tolar, 2007). These constructs were examined among two mathematics methods sections of secondary mathematics teachers in the New York City Teaching Fellows (NYCTF) program. The purpose of this study was to understand what mathematical content knowledge new teachers have both before and after a mathematics methods course, as well as what attitudes and concepts of self-efficacy these new teachers held. The need for this study is addressed first, followed by background on the NYCTF program. Second, the literature is examined for teacher quality in alternative certification, specifically in the NYCTF program. Next, the methodology and results are presented, and finally the results are discussed in connection to the literature and the implications of this research.

Need for the Study

Teacher content knowledge is important because it is a necessary, but not sufficient, condition for good teaching (Ball et al., 2005). Attitudes toward mathematics are important because there is a reciprocal relationship between attitudes toward mathematics and achievement in mathematics (Aiken, 1970, 1974, 1976; Evans, 2007; Ma & Kishor, 1997). Further, negative teacher attitudes toward mathematics often lead to avoidance of teaching strong mathematical content and affect students' attitudes and behaviors (Amato, 2004; Leonard & Evans, 2007). Poor attitudes toward teaching are directly related to teacher retention issues (Costigan, 2004). Moreover, there has been little published on the effects of field experience on new mathematics teacher content knowledge and attitudes (Evans, 2009; Leonard & Evans, 2008; Philipp et al., 2007). Philipp et al. found that preservice teachers with field experience at the elementary level showed an increase in content knowledge and positive beliefs, while those who did not have field experience did not show this increase. Further, it has been shown that teacher self-efficacy influences student achievement (Swars et al., 2007). However, the literature has been sparse in addressing in-service secondary mathematics teachers' knowledge, attitudes toward mathematics, and self-efficacy, particularly in alternative certification and secondary education. This study expands upon the literature by examining the field experience relationship, specifically in-service teaching, and experience in a reformed-based secondary mathematics methods course with content knowledge, attitudes toward mathematics, and self-efficacy in an alternative certification program.

NYCTF Program

The NYCTF program is an alternative certification program developed in conjunction with The New Teacher Project and the New York City Department of Education in 2000 (Boyd, Lankford, Loeb, Rockoff, & Wyckoff, 2007). The objective was to recruit professionals from other fields to alleviate the teacher shortages in New York City's public schools. At the outset of the program, there was a 7,000 teacher shortage expected in 2000 and a possible shortage of 25,000 teachers over the following several years (Stein, 2002).

Every year, new Teaching Fellows who are scheduled to start teaching in September begin graduate coursework at one of several New York universities in mid-June, and they begin student teaching in July. During the summer months, Teaching Fellows are given a stipend and receive subsidized tuition. Their full-time in-service teaching assignments begin in September, which is soon after beginning the program in the summer, while they continue taking graduate courses at their partnering universities. Before becoming certified, Teaching Fellows receive a Transitional B license from the New York State Education Department that allows them to teach for three years. Before teaching in September, Teaching Fellows must pass the Liberal Arts and Sciences Test and the Content Specialty Test in mathematics required by New York State. Further, Teaching Fellows generally teach in high-needs urban schools throughout the city (Boyd, Grossman, Lankford, Loeb, & Wyckoff, 2006).

The Teaching Fellows program grew very quickly during its first several years. "Fellows grew from about 1 percent of newly hired teachers in 2000 to 33 percent of all new teachers in 2005" (Boyd et al., 2007, p. 10). Teaching Fellows currently account for one-fourth of all New York City mathematics teachers (NYCTF, 2011a), and currently there are about 9,000 Teaching Fellows teaching in New York (NYCTF, 2011b). The Teaching Fellows program represents the largest alternative certification program in New York (Kane, Rockoff, & Staiger, 2006).

Alternative Certification Teacher Quality

There has been a recent interest in studying the effects of alternative teacher certification in U.S. classrooms with a particular interest in teacher quality issues (Darling-Hammond, Holtzman, Gatlin, & Heilig, 2005; Evans, 2009; Humphrey & Wechsler, 2007). Further, there has been specific interest in Teaching Fellows in New York City schools in particular (Boyd et al., 2006; Boyd, Grossman, et al., 2006; Boyd et al., 2007; Cicchelli & Cho, 2007; Costigan, 2004; Kane et al., 2006; Stein, 2002). However, most studies investigated student achievement and teacher retention to determine teacher quality and success. Naturally, these are two of the most important variables, but there is a need to investigate neglected variables in alternative certification that affect teacher quality such as teacher content knowledge, attitudes toward mathematics, and self-efficacy. A brief summary of three studies is presented, with the first two focused primarily on student achievement, and the third focused on attitudes toward teaching. Lastly, a summary of teacher retention findings is presented.

Boyd et al. (2006) examined the various pathways to become a teacher in New York City with particular focus on alternative certification. Like many other researchers, they focused primarily on student achievement and teacher retention as measures of success. Boyd et al. examined student achievement in grades 3–8 and found that, in the first year, alternatively prepared teachers had students with slightly lower achievement in mathematics compared with traditionally prepared teachers. There were no differences found in student achievement by the second year of teaching. However, in the third year of teaching, students of the alternatively prepared teachers had higher achievement than the students of traditionally prepared teachers.

Kane et al. (2006) also focused grades 3–8 and studied reading and mathematics scores on standardized state examinations. Kane et al. found that despite strong academic credentials, a variable related to teacher effectiveness, Teaching Fellows were no more effective than their traditionally certified colleagues. However, Kane et al. considered that new Teacher Fellows were occupied with graduate coursework, which allowed more time for traditionally prepared teachers to prepare for class. Kane et al. admitted that the time commitment to coursework could possibly hinder quality teaching considering available preparation time. It was concluded that "students assigned to teaching fellows [*sic*] performed similarly to students assigned to certified teachers in math . . . This average difference belies somewhat larger gaps among novice teachers . . . and no difference between teaching fellows [*sic*] and certified teachers with multiple years of experience" (Kane et al., 2006, p. 41).

Costigan (2004) examined Teaching Fellows' attitudes, particularly toward teaching, which is important

because teacher attitudes are directly related to teacher retention. Costigan sampled 38 Teaching Fellows to gather their written and verbal descriptions of their first-year experiences and found that, upon entering the program, Teaching Fellows generally had "rich beliefs and values about teaching" (p. 133) and appeared very optimistic about making a difference in their students. Teaching Fellows also expressed the common fear of poor student behavior and uncontrollable classes (Cruickshank, Jenkins, & Metcalf, 2006; Veenman, 1984), as well as poor support from administration. After beginning teaching, many Teaching Fellows expressed frustration with the lack of respect they received from their students. Costigan noticed a shift in topic in Teaching Fellows' journals from idealism and optimism to the practical concerns of the everyday classroom. Many Teaching Fellows expressed frustration that the material they learned in their methods courses was not useful for the realities of their own classrooms because the content they were teaching was at a lower level. As the year progressed, Teaching Fellows expressed more comfort in the classroom; and by the end of the year, the concern appeared to be more about teacher autonomy in the classroom instead of behavioral management issues.

A concern with alternative certification is lack of retention (Darling-Hammond et al., 2005), especially in large urban areas such as New York City. Results from the literature have been varied. Stein (2002) found 90% of surveyed Teaching Fellows said they were considering leaving their high-needs schools for better schools in or outside of New York, or leaving the teaching profession altogether. Contrary to Stein's findings, Sipe and D'Angelo (2006) found 70% of surveyed Teaching Fellows intended to remain in teaching. Further, the NYCTF program reported that 92% of Teaching Fellows who begin teaching teach at least one year, 75% teach at least three years, and half teach at least five years (NYCTF, 2011b). Boyd et al. (2006) found that about 46% of Teaching Fellows remained in teaching after four years, which compares from 55 to 63% of traditionally prepared teachers who remained. Other studies found that alternatively certified and traditionally prepared teachers had similar retention rates (Kane et al., 2006; Tai, Liu, & Fan, 2006).

From the literature, it is clear that there has been research conducted on Teaching Fellows' success as measured by student achievement and teacher retention. However, there have not been any known studies that specifically focused on the combination of mathematics content knowledge and self-efficacy and very little that substantially addressed the attitudes of Teaching Fellows. Additionally, an emphasis on secondary mathematics is needed because many studies have focused on teachers in elementary and middle schools. Humphrey and Wechsler (2007) called for more research into alternative certification pathways: "Clearly, much more needs to be known about alternative certification participants and programs and about how alternative certification can best prepare highly effective teachers" (p. 512).

Theoretical Framework

Aiken (1970, 1974, 1976) was an early pioneer to examine the relationship between mathematical achievement and attitudes toward mathematics. Aiken (1970) showed that attitudes and achievement in mathematics are reciprocal. Ma and Kishor (1997) found a small but positive significant relationship between achievement and attitudes through meta-analysis. This relationship, along with Ball et al.'s (2005) emphasis on the importance of content knowledge for teachers, formed the framework of this study. Ball et al. said, "How well teachers know mathematics is central to their capacity to use instructional materials wisely, to assess students' progress, and to make sound judgments about presentation, emphasis, and sequencing" (p. 14). Further, Ball et al. suggested that teachers with high content knowledge could help narrow the achievement gap in urban schools. High-needs urban schools in New York City are where Teaching Fellows are most often placed.

Additionally, Bandura's (1986) construct of self-efficacy theory framed this study's focus on self-efficacy in Teacher Fellows. Bandura found that teacher self-efficacy can be subdivided into a teacher's belief in his or her ability to teach well and his or her belief in affecting student learning outcomes. Teachers who feel that they cannot effectively teach mathematics and affect student learning are more likely to avoid teaching from an inquiry and student-centered approach with real understanding (Swars, Daane, & Giesen, 2006).

This current study was grounded in this literature (Aiken, 1970, 1974, 1976; Ball et al., 2005; Bandura, 1986; Ma & Kishor, 1997; Swars et al., 2006) because the three constructs are integral to the teaching and learning process for teachers and their students. Teachers with higher levels of content knowledge, attitudes toward mathematics, and self-efficacy are better

able to produce higher student achievement than teachers with lower levels. This study expands upon the literature by examining the three constructs among new in-service alternatively certified teachers.

Research Questions

The significance of the following research questions is that the Teaching Fellows program is a large alternative certification program with an emphasis on urban education. These teachers may be different than traditionally prepared teachers because of the manner in which they enter the profession along with the different backgrounds they bring. Teaching Fellows are often placed in high-needs urban schools where strong teacher preparation is critical (Ball et al., 2005). It would be valuable for researchers, teacher educators, and other stakeholders to know Teaching Fellows' level of mathematical content knowledge, attitudes toward mathematics, and self-efficacy before and after taking a reformed-based mathematics methods course while they are in-service teachers. Any differences found over the course of the semester in a reformed-based mathematics course provide valuable information to researchers and teacher educators about this unique group.

1. What differences existed between Teaching Fellows' mathematical content knowledge before and after a reformed-based mathematics methods course that focused on problem solving and understanding combined with in-service teaching?

2. What differences existed between Teaching Fellows' attitudes toward mathematics before and after a reformed-based mathematics methods course combined with in-service teaching? Further, what level of attitudes toward mathematics did Teaching Fellows possess at the end of the semester?

3. What differences existed between Teaching Fellows' self-efficacy before and after a reformed-based mathematics methods course combined with in-service teaching? Further, what levels of self-efficacy did Teaching Fellows possess at the end of the semester?

4. Was there a relationship between in-service Teaching Fellows' attitudes toward mathematics and self-efficacy at the beginning and end of a reformed-based mathematics methods course?

5. What were Teaching Fellows' attitudes toward teaching and learning mathematics over the course of a reformed-based mathematics methods course combined with in-service teaching?

Methodology

The methodology of this study was mixed involving both quantitative and qualitative methods. The sample in this study consisted of 42 new in-service teachers in the Teaching Fellows program enrolled in two reformed-based mathematics methods sections with approximately one-third of participants male and two-thirds of participants female. The teachers in this study were selected as a result of availability and thus represent a convenience sample. The reformed-based mathematics methods course, a class with a constructivist orientation aligned with the National Council of Teachers of Mathematics (NCTM, 2000) *Principles and Standards for School Mathematics*, involved both pedagogical and content instruction. There was a strong emphasis on mathematics for understanding with problem solving and a strong emphasis on numeracy. Each class began with a problem-solving situation for the teachers to solve collaboratively. Further, teachers practiced what they learned by presenting microteaching sessions throughout the semester. Topics in mathematical content were selected to facilitate conceptual, rather than only procedural, knowledge of the subject. Current research in mathematics education was addressed though literature critiques conducted and discussed by Teaching Fellows.

Teaching Fellows were given a mathematics content knowledge test and two questionnaires at the beginning and the end of the semester. The mathematics content test consisted of 25 free-response items ranging from algebra to calculus. In this study, mathematical content knowledge is the combination of knowledge, skills, and understanding of mathematical concepts held by teachers. The test taken at the end of the semester was similar in form and content to the one taken at the beginning.

The first questionnaire was from Tapia (1996) and had 40 items that measured attitudes toward mathematics including self-confidence, value, enjoyment, and motivation in mathematics. In this study, attitude toward mathematics is the sum of the teachers' positive and negative feelings toward mathematics in terms of self-confidence, value, enjoyment, and motivation. The instrument used a five-point Likert scale ranging from strongly agree, agree, neutral, disagree, to strongly disagree. The second questionnaire was adapted from the Mathematics Teaching Efficacy Beliefs Instrument (MTEBI) developed by Enochs, Smith, and Huinker (2000), and it measured teacher self-efficacy. The MTEBI is a 21-item five-point

Likert scale instrument with choices ranging from strongly agree, agree, uncertain, disagree, to strongly disagree, and it was grounded in the theoretical framework of Bandura's (1986) self-efficacy theory. Based on the Science Teaching Efficacy Belief Instrument developed by Enochs and Riggs (1990), the MTEBI contains two subscales: Personal Mathematics Teaching Efficacy (PMTE) and Mathematics Teaching Outcome Expectancy (MTOE) with 13 and eight items, respectively. Possible scores range from 13 to 65 on the PMTE, and 8 to 40 on the MTOE. The PMTE specifically measured a teacher's self-concept of his or her ability to effectively teach mathematics well, while the MTOE specifically measured a teacher's belief in his or her ability to directly affect student learning outcomes despite external factors in the students' lives.

Teaching Fellows were also required to keep reflective journals on their teaching and learning over the course of the semester, which provided qualitative data on their attitudes toward teaching and learning mathematics. The teaching journal was used as a reflection upon the Teaching Fellows' actual teaching and classroom experiences. As part of the mission in the school of education where this study took place, teachers are required to be reflective practitioners. The teaching journal had guiding questions such as the following: How are your students learning?; What challenges do you face?; and What successes have you had? The learning journal was used as a reflection of what was being learned in the mathematics methods course. The learning journals had guiding questions such as the following: How has this course affected your teaching?; What has been helpful?; and What are the most important concepts you've learned in this class? Additionally, the final item on the final examination in the methods class required the Teaching Fellows to state and to justify their own positions toward teaching mathematics on a scale ranging from a traditional back-to-basics approach to a reformed-based constructivist approach.

Research question one was answered using data collected from the mathematics content test. A paired samples *t*-test was used to determine if any significant increase occurred over the course of the semester. The results of the data analysis from the attitudinal and self-efficacy instruments were used to answer research question two and three, respectively. Paired samples *t*-tests were used to determine any significant attitudinal and self-efficacy differences over the course of the semester. Additionally, independent samples *t*-tests were used to answer the second part of research questions two and three. The fourth research question was answered using Pearson correlations. Research question five was answered qualitatively using the teaching and learning journals and final question on the final examination.

Limitations

The major limitation in this study was the role of the teacher-researcher. The instructor in the mathematics methods courses was also the researcher in this study. Therefore, consideration must be given for possible bias in student reporting because the students in this study knew the instructor would be conducting the research. Additionally, as in all survey research, internal validity issues arise because of student self-report. There is no reason to believe that students were not honest in their responses because they were assured their responses would not affect the outcomes in the course. The only issue might pertain to the final item on the final examination because students were graded on the justifications for their positions. Results from this analysis should be interpreted with caution.

Finally, as previously mentioned, the sample in this study consisted of a convenience sample as a result of availability, and the sample restricts the generalizability of this study. It would be beneficial for Teaching Fellows' content knowledge, attitudes toward mathematics, and self-efficacy to be studied with randomly selected larger samples in future research.

Results

To determine internal reliability of the attitudinal instruments, a Cronbach alpha coefficient was found to be 0.93 on the pretest and 0.94 on the posttest for the 40-item attitudinal test. These values are consistent with the literature (Tapia, 1996). For the self-efficacy pretest, Cronbach's alpha was found to be 0.80 for the PMTE and 0.77 for the MTOE, respectively. For the self-efficacy posttest, Cronbach's alpha was found to be 0.82 for the PMTE and 0.83 for the MTOE, respectively. These values are consistent with the values found by Enochs et al. (2000).

The first and second research questions were answered using the mathematics content test and the attitudes toward mathematics survey instrument, respectively. Data were analyzed using paired samples *t*-tests (see Table 1). For both the content

Table 1
Paired Samples t-Test Results for Content Test and Attitudes Toward Mathematics Test

Assessment	Mean	*SD*	*t*-value	Effect Size
Content test				
Pretest	74.79	17.605	–6.002**	.86
Posttest	84.48	14.225		
Attitudinal test				
Pretest	3.25	.373	–2.041*	.20
Posttest	3.33	.410		

Note. $N = 42$, $df = 41$, two-tailed.
** $p < .01$
* $p < .05$
SD = standard deviation.

Table 2
Independent Samples t-Test Results for Attitudes Toward Mathematics Test

Assessment	Mean	*SD*	*t*-value	Effect Size
Attitudinal test				
Actual posttest scores	3.33	.410	21.109**	4.89
Neutral scores	2.00	.000		

Note. $N = 42$, $df = 41$, two-tailed.
Equal variances not assumed.
** $p < .01$
SD = standard deviation.

test and the attitudinal instrument, there were statistically significant differences in scores over the course of the semester. The effect size was large for the content test and small for the attitudes toward mathematics instrument.

The second part of the second research question was answered using an independent samples *t*-test to determine if the participants had significantly better attitudes toward mathematics at the end of the semester as compared with neutral values coded as "2" on the survey sheet (see Table 2). Likert scores for strongly disagree, disagree, neutral, agree, and strongly agree were coded from 0 to 4. The participants had statistically significant more positive attitudes toward mathematics than neutral values of "2," and the effect size was very large. Comparing actual attitudinal scores with neutral responses should be interpreted with caution.

The third research question was answered using the MTEBI with two subscales: PMTE and MTOE. Data were analyzed using paired samples *t*-tests. The results of the paired samples *t*-test (two-tailed) revealed no statistically significant difference between pretest scores and posttest scores for both the PMTE and MTOE, respectively. This means there were no increases in self-efficacy over the course of the semester.

The second part of the third research question was answered using independent samples *t*-tests to determine if the participants had significantly better concepts of self-efficacy at the end of the semester as compared with neutral values coded as "2" on the survey sheet (see Table 3). For both the PMTE and the MTOE, the participants had statistically significant more positive concepts of self-efficacy than neutral values of "2," and the effect sizes were very

Table 3
Independent Samples t-Test Results for MTEBI (PMTE and MTOE)

Assessment	Mean	*SD*	*t*-value	Effect Size
PMTE				
Actual posttest scores	2.94	.486	12.565**	2.73
Neutral scores	2.00*	.000		
MTOE				
Actual posttest scores	2.74	.505	9.513**	2.07
Neutral scores	2.00	.000		

Note. $N = 42$, $df = 41$, two-tailed.
Equal variances not assumed.
** $p < .01$
SD = standard deviation.

Table 4
Pearson Correlations between Attitude Scores and PMTE Scores

Assessment	Mean	*SD*	*r*-value
Pretest attitudinal test	3.25	.373	.690**
Pretest PMTE	2.90	.435	
Posttest attitudinal test	3.33	.410	.491**
Posttest PMTE	2.94	.486	

Note. $N = 42$, $df = 41$
** $p < .01$
SD = standard deviation.

large. Pearson correlations were used to answer research question four (see Table 4). It was found that there were statistically significant correlations between pretest mathematics attitude scores and pretest PMTE scores and between posttest mathematics attitude scores and posttest PMTE scores. No significant correlations were found between mathematics attitude scores and MTOE scores.

The fifth research question was answered using Teaching Fellows' teaching and learning journals and their responses to the final item on the final examination. Analysis of the teaching journals revealed that the most commonly addressed topic was classroom management. Several Teaching Fellows mentioned that classroom management was not as much an issue as they thought it would be. However, most of the Teaching Fellows believed that classroom management issues were of their highest concern. Two Teaching Fellows were physically threatened by students, which was of great concern for both of them. One student felt that she was unprepared to deal with the classroom management issues that she encountered. After classroom management, student motivation and attendance issues were also addressed by the Teaching Fellows. Further, students' lack of basic skills, collaborative learning in the classroom, time management issues, and student lack of conceptual understanding were issues addressed in the teaching journals. Overall, it appeared that Teaching Fellows generally believed their classroom experiences were good, and that they were able to positively affect student learning. The results of research question three reported that PMTE and MTOE scores did not increase over the course of the semester. However, it was found that at the end of the semester, Teaching Fellows had high self-efficacy. This finding was further triangulated with the teaching journals.

Analysis of the learning journals revealed that the most commonly addressed topics were problem solving and numeracy. Because the reformed-based mathematics methods course was taught from a problem-solving perspective, Teaching Fellows were given a "problem of the day" that they solved collaboratively at the beginning of each class. Problem solving as a way of teaching was thoroughly addressed in the course with considerable time devoted to problem solving in teachers' classrooms. It should be noted that one student stated that even though he

enjoyed the problem-solving aspect of the course, he felt that too much time may have been spent on it. Further, in addition to the mathematics methods textbook (Posamentier, Smith, & Stepelman, 2006), Teaching Fellows read Paulos' (1990) *Innumeracy: Mathematical Illiteracy and Its Consequences*. In this book, Paulos addressed what it means to be numerate (i.e. mathematically literate) in a democratic society. Furthermore, Teaching Fellows thought microteaching and motivation techniques enhanced their learning in the course. Every Teaching Fellow was required to present a brief microlesson that contained a motivator intended to gain student interest. Because teachers felt they had trouble motivating their students, many found microteaching and general motivational techniques covered in this course to be helpful. One student mentioned that at times the course was more theoretical and less practical than she would have preferred (Costigan, 2004).

Teaching Fellows' teaching philosophies were ranked as either traditional, moderate, or reformed, and Teaching Fellows were graded based upon their justification for their positions. Five Teaching Fellows had traditional views, 23 had moderate views, and 14 had reformed views. However, there was some overlap of the teachers' views. Of the five traditionally oriented Teaching Fellows, one stated that he could understand other views but held to the traditional view of teaching. Of the 23 moderate-oriented Teaching Fellows, two stated that they could understand the traditional view of teaching. Further, four said they could understand the reformed approach. One of those four in particular said that she could better understand the reformed approach since taking the methods course. Of the 14 reformed-oriented Teaching Fellows, five said they could understand the moderate approach. An additional student said she could understand why a teacher would lean toward the traditional approach despite feeling that she is a believer in reformed-based methods.

Teaching Fellows justified traditional views based upon how they learned mathematics (Osisioma & Moscovici, 2008). These Teaching Fellows expressed doubts about the effectiveness of reformed-based teaching strategies and methodologies, and they expressed comfort with traditional teaching methods. Teaching Fellows justified moderate views based upon reformed-based methodology research, the methods course textbook, and the methods class in general. Similar to the traditionally oriented Teaching Fellows, they relied upon the way they learned mathematics and their comfort level in teaching. Finally, Teaching Fellows justified reformed-based views similarly to those with moderate views by relying on research and the methods class, which was taught from a reformed-based perspective.

Discussion

It was found that Teaching Fellows increased their mathematical content knowledge over the course of a one-semester reformed-based mathematics methods course while teaching in their own classrooms. Additionally, it was found that Teaching Fellows had an increase in positive attitudes toward mathematics over the course of the semester; and at end of the semester, they generally held positive attitudes toward mathematics. It is speculated that a reformed-based mathematics methods course with an emphasis on mathematics for understanding and problem solving, combined with in-service teaching experiences, contributed to the growth of teacher content knowledge and better attitudes toward mathematics (Palmer, 2006). Content knowledge in secondary level teaching is important because the mathematics required is more sophisticated than at the elementary level. Prior research primarily focused on the elementary level. Because Teaching Fellows come to the profession without mathematics majors in many cases, content knowledge is of particular concern. The results of this study should help alleviate some of the concern that alternatively certified teachers are unprepared to teach because it has been shown that a reformed-based methods course and in-service teaching can lead to immediate growth in content knowledge and positive attitudes toward mathematics as measured in this study.

No increase was found in teacher self-efficacy on both the PMTE and MTOE subscales. However, it was found that at the end of the semester, Teaching Fellows generally had high concepts of self-efficacy both in terms of their ability to teach well (as measured by the PMTE), as well as their ability to positively affect student outcomes (as measured by the MTOE). Additionally, evidence from Teaching Fellows' journals further indicated high concepts of self-efficacy. Because teachers already had high self-efficacy, it is not very surprising that there were not significant increases in self-efficacy. However, these results are inconsistent with the literature and thus inconclusive (Palmer, 2006; Swars et al., 2007). Findings in the

literature suggested that over the course of a methods course, teacher efficacy increased. Further, Hoy and Woolfolk (1990) reported that teacher outcome expectancy declined when preservice teachers began teaching. However, teacher outcome expectancy in the literature had been examined for teachers transitioning from preservice to in-service. The participants in this study began as in-service teachers, which mean they encountered the realities of the classroom immediately. The self-efficacy aspect for in-service teaching should be further investigated, particularly at the secondary level.

A positive correlation was found between Teaching Fellows' attitudes toward mathematics and PMTE scores for both pre and posttests. However, no relationship was found for attitudes toward mathematics and MTOE. This is consistent with the literature (Swars et al., 2006) when examining the relationship between mathematics anxiety and self-efficacy using the PMTE and MTOE subscales. Mathematics anxiety has been shown to be related to attitudes toward mathematics (Ma, 1999). This study indirectly and partially confirms the findings of Swars et al. (2006) at the secondary level for in-service teachers.

It was found that Teaching Fellows generally stated that classroom management was the biggest issue in their teaching, and that problem solving and numeracy were the most important issues addressed in the methods course. It was not surprising that teachers found classroom management to be the biggest issue because this is consistent with the literature for new teachers (Costigan, 2004; Cruickshank et al., 2006; Veenman, 1984). However, it was surprising that several teachers stated that classroom management was not an issue for them. This is in contrast to contrary findings with Teach for America alternative certification (Evans, 2009), in which classroom management was exclusively problematic. Finally, it was expected that teachers would find problem solving and numeracy to be two of the most valuable topics addressed in the course because there was a strong emphasis placed on both in the course.

The results of this study contribute to the literature because of the unique sample that was investigated. The teachers in this study came to the profession differently than traditionally prepared teachers, and these teachers were considered to be "career-changers." There is concern about the lack of content knowledge held by these teachers because many did not study mathematics extensively as undergraduates as many traditionally prepared teachers did. The findings in this study suggest that teachers improved their content knowledge and attitudes toward the subject after taking a reformed-based mathematics methods course. This has implications for the future preparation of alternatively certified teachers because it showed that a reformed-based methods course coupled with in-service teaching can have a significant impact on content knowledge and attitudes toward mathematics. It is suggested that more mathematics and/or methods courses be included in teacher preparation programs for alternative certification teachers. Future studies should examine mathematics content knowledge using content subcategories and in various domains and examine the impact of this knowledge on student learning in the classroom.

The results of this study further contribute to the literature because teachers demonstrated high self-efficacy at the end of the mathematics course. Considering the participants were in-service teachers, this has interesting implications about the teacher preparatory program because the literature showed teachers tend to have higher levels of student outcome expectancy while they were preservice teachers. However, outcome expectancy generally declined when the teachers become in-service and the realities of the classroom are encountered (Swars et al., 2007). Secondary alternative certification teachers' student outcome expectancy should be further investigated in future research. Also, future studies should determine if attitudes toward mathematics and concepts of self-efficacy are durable and sustained over time. Palmer (2006) examined the durability of self-efficacy in elementary science teachers, but this durability should be investigated for secondary mathematics teachers as well. Finally, the impact of attitudes toward mathematics and self-efficacy on student learning in the classroom should be investigated in future research.

It is hoped that there will continue to be more studies at the secondary level on alternative certification, specifically in the Teaching Fellows mathematics program. Understanding teachers' mathematics content knowledge, attitudes toward the subject, and self-efficacy is important for professors of education to guide teacher education instruction as well as provide much needed support for new teachers. This is more critical now than ever, considering the ever increasing pool of New York

mathematics teachers who enter the profession through the Teaching Fellows program and other alternative certification programs elsewhere throughout the United States. Teacher quality in alternative certification has a direct impact on the many urban students who receive these new teachers in their classrooms. Given the rhetoric in education regarding equity and social justice, more studies are necessary on this unique group of teachers who teach urban students.

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Preservice Teachers' Beliefs and Attitude About Teaching and Learning Mathematics Through Music: An Intervention Study

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This article presents exploratory research investigating the integration of music and a mathematics lesson as an intervention to promote preservice teachers' attitude and confidence and to extend their beliefs toward teaching mathematics integrated with music. Thirty students were randomly selected from 64 preservice teachers in a southern university. A 90-minute mathematics lesson integrated with a music composition activity was taught by the first author. Pre- and postquestionnaires were provided to evaluate the change in preservice teachers' attitude and beliefs toward mathematics. The results demonstrated that the mathematics lesson integrated with music had a positive effect on preservice teachers' attitude and beliefs toward mathematics teaching and learning.

Both the National Council of Teachers of Mathematics (NCTM, 2000) and the National Consortium of Arts Education Associations (1994) in their standards explicitly documented that all students from kindergarten to 12th grade should be able to recognize and apply knowledge to other content areas (e.g., making connections between mathematics and the arts). Research has consistently found benefits of teaching mathematics connected with science and language arts in recent years (i.e., Keen, 2003; Marrongelle, Black, & Meredith, 2003). These connections provided opportunities for students to make sense of mathematics and to apply mathematical knowledge in meaningful ways when connecting new knowledge to existing knowledge (Schoenfeld, 1988). One of the methods in teaching mathematics was to integrate arts as a catalyst for mathematics learning (Betts, 2005).

Expanding Preservice Teachers' Pedagogical Content Knowledge

According to previous studies, pedagogical content knowledge was a major component of teachers' knowledge (e.g., Fennema & Franke, 1992; Shulman, 1986). For preservice teachers, their pedagogical content knowledge, or knowledge of teaching and learning, influenced their future teaching behavior (Dooren, Verschaffel, & Onghena, 2002). However, a major challenge for teacher preparation programs was to prepare preservice teachers with pedagogical content knowledge (Niess, 2005). Lacking experiences in classroom teaching, preservice teachers need guidance with regard to how to learn and develop their pedagogical content knowledge, the central component of teachers' practical knowledge (Niess; Van Driel, Verloop, & De Vos, 1998).

In recent years, traditional teacher preparation programs have often been criticized for being excessively theoretical, having little connection with practice, offering fragmented courses, and lacking a clear conception of teaching (Darling-Hammond & Baratz-Snowden, 2007). The NCTM (2000) standards advocated an emphasis on teaching mathematics with understanding. Many preservice and in-service teachers, however, had difficulty adopting this focus in teaching practices despite their enthusiasm for reform (Hiebert & Stigler, 2000). The NCTM's Equity Principle requires teachers to develop effective methods for supporting the learning of mathematics for all students: Regardless of students' personal characteristics, backgrounds, or physical challenges, teachers should provide opportunities and support for all students in mathematics learning. The goal of success for all can be achieved by providing opportunities for students to experience the esthetics of arts in mathematics learning (Betts & McNaughton, 2003; Eisner, 2002).

Reducing Preservice Teachers' Mathematics Anxiety

Researchers have identified two components comprising mathematics anxiety (Morris, Davis, & Hutchings, 1981): (a) cognitive—including the worrisome

thinking about personal performance, and (b) potential negative consequences and emotions—including nervousness, fear, and discomfort when involved in mathematical-related tasks (Vance & Watson, 1994). As a unique group of college students containing a high percentage of females, preservice teachers, compared with their peers from other majors, have poorer attitudes and higher anxiety toward mathematics (Bursal & Paznokas, 2006). Even worse is that preservice teachers may transmit this negative attitude toward mathematics to students in their future classrooms (Furner & Berman, 2005).

Traditional ways of teaching mathematics is considered one of the key factors that caused mathematics anxiety: Assigning the same problem to every student, teaching through lecturing by the textbook, insisting on the only one way to solve problem, neglecting conceptual understanding, and others were argued as the origins of mathematics anxiety (Furner & Berman, 2005). Teaching mathematics in nontraditional ways such as using problem-solving activities, simulations, discoveries, challenges, and games was proposed as effective methods in reducing students' mathematics anxiety (Tobias, 1998). Researchers suggested that in order to reduce preservice teachers' mathematics anxiety as well as to develop a positive attitude toward mathematics, teacher educators should demonstrate various mathematical strategies for preservice teachers with an emphasis on teaching through manipulatives and real-life activities that focus on conceptual understanding (Bursal & Paznokas, 2006; Gresham, 2007).

Teaching Mathematics Connected With Arts

The link between music and mathematics has deep historical roots. In the sixth century BC, the Greek philosopher Pythagoras found the ratio among music intervals. For example, the corresponding ratio between the intervals of an octave is 1:2, whereas that between the intervals of a fifth is 2:3 (Ferreira, 2002). However, as an essential part of arts, music, along with literature and visual arts, was rarely found integrated into mathematics lessons (Johnson & Edelson, 2003; Rothenberg, 1996). Also, even existing ways of teaching mathematics through music were usually only superficially focused on the relationship between mathematics and music, such as counting rhythms or learning the fractional nature of note values (Rogers, 2004).

Music is related internally and externally to mathematics from multiple perspectives. Mathematical knowledge existed from the kindergarten to the university levels and can be used from basic music elements to whole works (Fauvel, Flood, & Wilson, 2003; Harkleroad, 2006; Loy, 2006). For example, notes, intervals, scales, harmony, tuning, and temperaments are related with proportions and numerical relations, integers, logarithms and arithmetical operations, trigonometry, and geometry (Beer, 1998; Harkleroad). Melody and rhythm can be represented mathematically, and music forms can also be represented by mathematical patterns (Beer). The mathematical concepts of the *Fibonacci sequence* and the *Golden Section* theory were also used by some music composers (Garland & Kahn, 1995; May, 1996).

Fiske (1999) summarized and demonstrated that teaching through the arts can (a) transform learning environments; (b) reach students who may not be easily reached; (c) promote communication among students; (d) provide opportunities for adults' involvement; (e) offer new challenges for successful students; and (f) connect learning experiences from school to the world.

Recent research has reported beneficial results not only for students with special characteristics but also for all students learning mathematics and other subjects when integrating topics with arts: (a) significant enhancement in students' attitudes and beliefs toward learning mathematics (An, Kulm, & Ma, 2008); (b) effective motivation in students' engagement in mathematics (Shilling, 2002); (c) remarkable improvement in understanding mathematics (Autin, 2007; Peterson, 2005); (d) development in cognitive ability (Eisner, 1985; Peterson); (e) improvement in critical thinking and problem-solving skills (Wolf, 1999); (e) development of ability to work collaboratively in groups (MacDonald, 1992; Wolf); (f) enhancement in students' self-confidence (MacDonald); (g) improvement of empathy and tolerance in class (Hanna, 2000); (h) improvement in mathematics achievement (Harris, 2007); (i) development of the imagination (Greene, 2001); (j) improvement of motivation for learning (Csikszentmihalyi, 1996); and (k) increase in students' creativity and social skills and decrease in dropout rates (Catterall, 2005).

The current study was characterized by a sequence of classroom activities aimed at reinforcing preservice teachers' beliefs and pedagogical content knowledge specifically on teaching mathematics integrated with music. We demonstrated how a suitable musical composition activity incorporated with mathematics can

play a fundamental role in bringing preservice teachers' mathematical reasoning experiences into play by creating a new tension between school mathematics and music. The overarching goal of the activity was to examine the relationship between music and school mathematics and the ways each can inform the other in the development of abstract mathematical knowledge. In this case, the focus was on understanding aspects of the multiplicative structure of problem solving. More specifically, the research questions were (a) What are the effects of mathematics–music connection activities on preservice teachers' engagement, confidence, attitude, and beliefs toward teaching and learning mathematics? and (b) How do preservice teachers' beliefs change as a result of experiencing teaching and learning mathematics integrated with music?

Theoretical Framework

With the adoption of the theoretical framework used in the previous study (An et al., 2008), the current study is grounded on theories and research that suggest (a) focusing on the individual abilities of students from multiple intelligences theory to enhance classroom learning (Gardner, 1993) and (b) implicating motivation theory by teaching mathematics associated with creative and active involvement of aesthetics to provide a rich and emotionally stimulating mathematical learning context, reducing students' mathematics anxiety and engaging students in mathematics learning (Eisner, 2002; Sylwester, 1995; Upitis & Smithrim, 2003; West, 2000; Witherell, 2000).

Implications of Multiple Intelligences

Gardner (1983) argued that there are multiple intelligences among different learners, including linguistic, musical, logical-mathematical, spatial, bodily kinesthetic, interpersonal, and intrapersonal intelligences. All intelligences can route individuals through development and communication. The differences in intelligences can serve both as the content of instruction and as the means for communicating the content. Based on multiple intelligences, if a student had difficulties in understanding principles of content in mathematics, the teacher should provide an alternative route to develop conceptual understanding (Kassell, 1998). Embedding music activities into mathematics can not only increase students' mathematical understanding but also provide them an enjoyable means for developing logical/mathematical intelligences along with their musical/rhythmic intelligences (Shilling, 2002).

Greene (2001) defined learning through aesthetics as an "initiation into new ways of seeing, hearing, feeling, moving, a reaching out for meanings, a learning to learn integral to the development of persons—to their cognitive, perceptual, emotional, and imaginative development" (p. 7). Learning through arts allowed students to view the world from different perspectives and to experience rewards from success in mathematics through the arts (Gamwell, 2005). Gardner found that using music to enhance children's enjoyment and understanding of mathematical concepts and skills could help students gain access to mathematics through new intelligences. The arts enabled students to use different learning styles and prior knowledge, pulling together diverse cognitive and affective experiences and organizing them to assist understanding (Selwyn, 1993). As an application of multiple intelligence theory, teaching mathematics integrated with music facilitates students whose strengths lie in areas other than the logical-mathematical intelligence to learn mathematics more easily (Johnson & Edelson, 2003).

Implication of Motivation Theory

Pavlov (1927/1960) introduced the concept of motivation as a new habit that occurs when two stimuli are provided simultaneously. Motivation theory can provide a framework to facilitate students' learning and to interpret how students' learning is associated with their emotions and attitudes (Ormrod, 2008). Ormrod also suggested a key implication of the motivation theory that states that students should study in a positive learning climate and associate learning with positive emotions. According to motivation theory, when students have formed a new stimulus–response connection, for example, learning mathematics joyfully associated with an enjoyable arts environment, they will maintain their positive attitude as a conditioned response to the mathematics lessons as conditioned stimulus in the future.

Emotion is essential in students' learning because it focuses attention on learning (Sylwester, 1995). Arts bonded with emotions enabled students to express themselves and to communicate ideas (Stevens, 2002). As an application of motivation theory to reduce mathematical anxiety as well as to increase motivation and engagement, Miller and Mitchell (1994) suggested that teachers should create a positive learning environment, free from tension and other possible causes of embarrassment or humiliation. Arts, with its

aesthetical features, have the potential to provide students an enjoyable environment in which they can discover and think about mathematics concepts in various ways and can build fundamental understandings and appreciation for both mathematics and the arts (Lawrence & Yamagata, 2007). What is more, arts can provide students a learning environment with less prejudice and violence, helping them become better risk takers and communicators (Trusty & Oliva, 1994).

Methodology

Participants and Intervention Lesson

This study was guided by the first author's personal academic background of music and teaching experiences as a mathematics teacher and was carried out in a large, southern public university. Thirty (n = 30) middle school mathematics/science preservice teachers were randomly selected from N = 64 students who were enrolled in two sections of a required problem-solving course to participate in the present study. Students were mainly traditional and female matching the population of preservice teachers at the university. Random selection was accomplished by shuffling all the pre- and postquestionnaire sheets and by choosing 30 sheets from both the pre- and postquestionnaires.

All the preservice teachers (N = 64) participated in a 90-minute interactive intervention activity led by the first author between the pre- and postsurveys. Two worksheets were provided for preservice teachers to compose their own music and to answer mathematics problem-solving tasks. Crayons and a digital piano were prepared for the class. During the Microsoft PowerPoint-assisted lecture, fundamental music composition rules were presented on how to use graphic notation to compose music based on simple mathematical rules. Participants were then asked to use seven different color bars to represent music scales and the numbers of bars to represent the duration of notes. In this graphic notation system, red, white, yellow, blue, green, black, and purple were employed to represent C, D, E, F, G, A, and B in music. Chords (three or more different notes that sound simultaneously) were represented by different combinations of color. Based on a typical popular music chord sequence (sequenced as I, V, VI, III, IV, I, II, and V), preservice teachers learned to compose their own music by choosing colors from specific chords to fill in the first four blanks and choosing any color to fill in the following blanks in each music sentence (see Figure 1). After preservice teachers finished their music task, their compositions were played on the digital piano (see Figure 2)—the specific chord was played by the left hand and the preservice teachers' melody was played by the right hand. Preservice teachers enjoyed the performance by listening to and sharing their own musical creations with their classmates.

After listening to the preservice teachers' composition works, we assigned three problem-solving tasks for them to complete: (a) How many different combinations of songs will you have based on this composition rule? (b) If the song has 12 pieces, how many different structures may you have in your group? and (c) Alice composed three songs with time duration for each song of 7-piece composition (245 seconds), 11-piece composition (385 seconds), and 13-piece composition (455 seconds). Can she determine the time duration of a song with nine pieces?

Instruments and Data Collection

A week before the intervention lesson, all preservice teachers completed a survey measuring their

Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Purple	Blue
Red	Red	Red	Red	Red	Red	Purple	Green
Purple	Purple	Purple	Purple	Purple	Purple	Red	Yellow
Green	Green	Green	Green	Green	Green	Black	Green
White	White	White	White	White	White	Purple	Blue
Blue	Blue	Blue	Blue	Blue	Blue	Red	Black
Red	Red	Red	Red	Red	Red	Yellow	Blue
Black	Black	Black	Black	Black	Black	Green	Purple

Figure 1. A sample of students' composition work *Beautiful* presented by graphic notation.

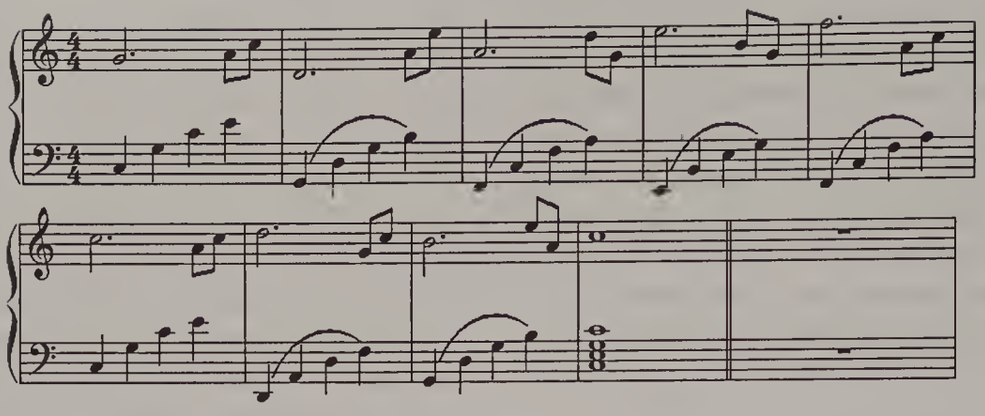

Figure 2. A sample of students' composition work *Beautiful* presented by grand staff.

beliefs about teaching and learning mathematics integrated with music. The same survey was collected as a posttest a week after the intervention lesson. The questionnaire (see Table 1) consisted of 20 closed-ended Likert items with five levels ranging from strongly disagree to strongly agree and two open-ended items. These items focused on four categories: items 1–4 were designed to assess preservice teachers' views about the engagement of mathematics; items 5–9 were designed to assess preservice teachers' beliefs toward mathematics as well as the relationship between music and mathematics; items 10–13 were designed to assess preservice teachers' attitude toward mathematics; and items 14–20 were designed to assess preservice teachers' confidence in mathematics learning. The two open-ended questions were designed to assess preservice teachers' beliefs toward teaching a mathematics lesson integrated with music.

Data Analysis

A paired-sample *t*-test was used to determine statistically significant differences in mean scores and standard deviations between pre- and posttests of the close-ended questionnaire, and a Bonferoni correction was employed because of using multiple univariate tests. The original alpha value was .05. After correcting for four paired *t*-tests, the new adjusted alpha for all tests was .025. Effect sizes were calculated for each category and expressed in Cohen's *ds* to determine whether those differences were important in educational terms (Capraro, 2004). For the open-ended questions, we coded, categorized, and compared students' responses (Lincoln & Guba, 1985) to analyze how preservice teachers' views on mathematics and the relationship between music and mathematics changed from pretest to posttest.

Results

The results of the paired-samples *t*-test displayed in Table 1 demonstrated that the means on all 20 items on the closed-ended questionnaire improved from the pretest to the posttest. The results showed that preservice teachers' engagement, beliefs, motivation, and confidence toward mathematics teaching and learning were statistically significantly improved from pretest to posttest. Additionally, the effect sizes for these four categories with significance were considered in the moderate to large range (67–.80), indicating that the intervention activity had a considerable educational impact on the preservice teachers. The reliability of the pretest calculated in coefficient alpha was .873 and .881 for the data in hand.

Statistically significant improvement was found for preservice teachers from pretest to posttest on the following factors: The *p* value for engagement in mathematics learning was .016 on items 1–4; the *p* value for beliefs toward mathematics teaching and learning was .003 on items 5–9; the *p* value for motivation in mathematics teaching and learning was .003 on items 10–13; and the *p* value for confidence in mathematics teaching and learning was .006 on items 14–20.

The results of the two open-ended questions demonstrated that the preservice teachers' beliefs toward teaching mathematics integrated with music and the relationship between mathematics and music experienced had considerable changes. In terms of open-ended question 1, "What is the relationship between music and mathematics?" (see Table 2), more responses were provided on the posttest than on the pretest. On the pretest, the total number of relationship themes mentioned by preservice teachers was eight,

Table 1
t-Test Results on Closed-Ended Questions of Preservice Teachers' Pretest and Posttest

—	Item	Pretest Mean ± *SD*	Posttest Mean ± *SD*	Cohen's *d*	*p* value	*t*
Engagement	1. Math class will be less boring if math can be integrated with music properly.	3.23 ± .97	3.93 ± .91	.67	.016	2.553
	2. Math class could be exciting and interesting if integrated with music.	3.60 ± 1.16	4.23 ± .94			
	3. Music can effectively motivate students to learn math.	3.80 ± 1.00	4.23 ± .86			
	4. Music is an effective method to engage students to learn math.	3.77 ± 1.10	4.33 ± .84			
Beliefs of math and music	5. Math should be taught connected with other math contents.	4.53 ± .73	4.57 ± .63	.80	.003	3.258
	6. Math should be taught integrated with other subjects.	4.53 ± .68	4.73 ± .52			
	7. Math and music have lots of relationships.	3.37 ± 1.16	4.43 ± .77			
	8. Music is an alternative way to help learners to understand math acoustically.	3.80 ± 1.03	4.13 ± 1.01			
	9. Math can be taught integrated with music.	3.73 ± 1.05	4.47 ± .78			
Attitude	10. I would feel happy if math class was integrated with music properly.	3.27 ± 1.08	4.00 ± 1.03	.78	.003	3.181
	11. Music can provide learners a joyful environment to learn math.	3.73 ± 1.11	4.47 ± .73			
	12. Math learners may feel less anxious if math is integrated with music.	3.33 ± 103	3.57 ± 1.04			
	13. Math is fun when integrated with music.	3.43 ± 1.07	4.26 ± .91			
Confidence	14. I think I can handle more difficult mathematics.	4.07 ± .87	4.17 ± .70	.68	.006	2.993
	15. I think I can handle more difficult mathematics if integrated with music.	3.13 ± .97	3.70 ± .95			
	16. I can teach mathematics better if I know how to integrate music into math.	3.17 ± 1.09	3.73 ± 1.23			
	17. It will be easy for a student to learn math if I teach math integrated with music.	3.06 ± 1.01	3.70 ± .99			
	18. I am confident in engaging my student to learn math by integrating it with music.	3.13 ± 1.07	3.50 ± .82			
	19. It would be great to receive more reward for my students when they achieving mathematics tasks.	4.13 ± .90	4.33 ± .66			
	20. I have confidence in teaching mathematics integrated with music.	2.83 ± 1.02	3.33 ± 1.06			

Note. $n = 30$.
SD = standard deviation.

Table 2
Preservice Teachers' Response on the Relationship Between Mathematics and Music

Category	Theme	Response Rate (n = 30) Pre (%)	Post (%)
Superficial relationship	Amount of measures	16.7	16.7
	Number of count beats (tempo or rhythm)	60	40
	Amount of notes	33.3	13.3
	Difference among pitch (addition in music scale)	10	23.3
	Fraction (ratio) among note values (time signature)	10	33.3
	Song words with math contents	6.7	3.3
Profound relationship	Patterns in music works	10	26.7
	Regulation in instrumentation	3.3	0
	Combination of notes in chords	0	30.3
	Formula in music composition	0	6.7
	Sequence in music arrangement	0	6.7
	Math problem designed based on music work	0	16.7
	Factor in music composition	0	3.3
	Statistics graph to analyze music work	0	6.7
	Multiplication, division, and power in composition	0	10
	Probability in composition	0	6.7
	Transposing among different keys	0	6.7
No idea	—	10	0

Note. n = 30.

and on the posttest, this number increased to 16; on the pretest, the total response rate of relationship themes mentioned by preservice teachers was 130%, and on the posttest, the response rate increased to 260.4%. Specifically, on the pretest, most answers that preservice teachers provided were categorized as superficial relationships based on their common sense and the obvious information from the music as well as the music sheets. Very few preservice teachers provided profound relationships based on advanced music knowledge integrated with complicated mathematics content. On the posttest, the amount of superficial relationships provided by the preservice teachers decreased; however, most preservice teachers provided some profound relationships demonstrating a deeper understanding of both mathematics and music.

In terms of open-ended question 2, "What is the mathematics content that can be taught by integrating music?" (see Table 3), more answers were given on the posttest than on the pretest. On the pretest, the total number of lesson themes mentioned by preservice teachers was eight, whereas on the posttest, this number increased to 17. On the pretest, the total response rate of relationship themes suggested by preservice teachers was 150%, while on the posttest, the response rate increased to 217%. Specifically, on the pretest, most lessons themes that preservice teachers described were based on basic musical knowledge integrated with simple mathematics content. Very few preservice teachers discussed lessons based on advanced musical knowledge integrated with complicated mathematics content. On the posttest, the

Table 3
Preservice Teachers' Response to Mathematics Content Taught by Integrating Music

Category	Theme	Response Rate (n = 30) Pre (%)	Post (%)
Basic music knowledge integrated with simple math content	Teach counting by count words in a song	6.7	0
	Teach counting by count notes (beats) in a music sheet	33.3	23.3
	Teach fraction with key signatures	3.3	3.3
	Teach ratio by compute beat per minute	16.7	6.7
	Teach fraction form note values and beat type	23.3	0
	Play music when students doing math works	3.3	3.3
	Put math contents into songs	30	3.3
	Teach time by playing songs	3.3	0
	Teach addition and subtraction from music composition	0	10
	Teach fraction from music composition	0	26.7
Advanced music knowledge integrated with complicated math content	Teach frequency from music composition	0	3.3
	Teach statistical chart from music composition	0	33.3
	Teach combination from music composition	0	33.3
	Teach pattern finding from music composition	0	40.0
	Teach sequences from music composition	0	3.3
	Teach problem solving from music composition	0	26.7
	Teach probability from music composition	0	30.0
No idea	—	0	6.7

Note. n = 30.

amount of some lesson themes based on basic music knowledge integrated with simple mathematics content decreased; however, most preservice teachers provided some lessons themes based on advanced musical knowledge integrated with complicated mathematical content.

Discussion

The present study seeks to investigate the effects of a mathematics–music-integrated intervention activity on preservice teachers' belief, confidence, motivation, and engagement toward teaching and learning mathematics. Consistent with previous research on the positive impact of a music-integrated mathematics intervention activity on elementary students' attitudes, confidence, and belief toward mathematics as well as learning mathematics (An et al., 2008), in the present study, preservice teachers' attitude, confidence, engagement, and beliefs toward learning and teaching mathematics also show significant positive shifts throughout the intervention.

Changes in Preservice Teachers' Mathematics Attitudes, Confidence, and Beliefs

In this study, we try to use aesthetics as a medium to present preservice teachers a music–mathematics-integrated activity in order to investigate the knowledge of teaching mathematics interestingly and meaningfully integrating with music. The improved scores for all items on the closed-ended questionnaire indicate that the mathematics activity integrating music not only improves preservice teachers' attitudes, engagement, and confidence but also changes

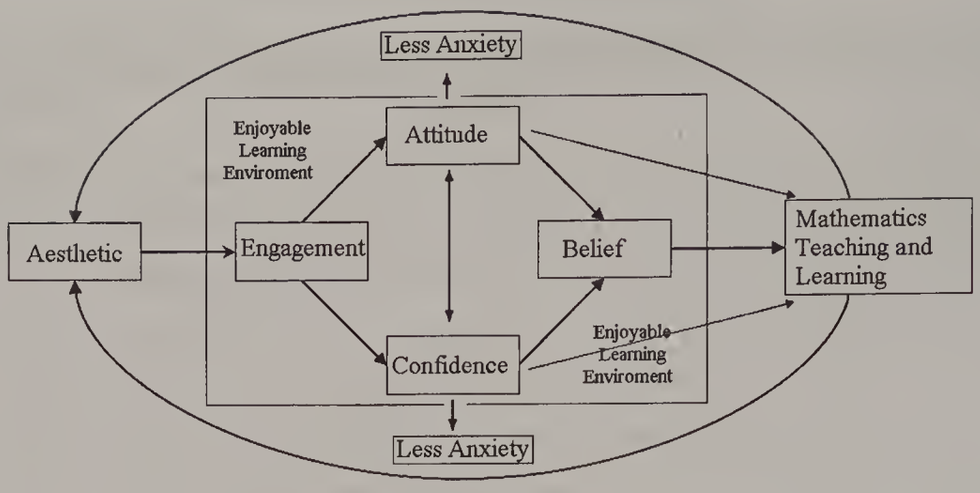

Figure 3. The process of improvement on preservice teachers' engagement, attitudes, confidence, and changes on beliefs toward mathematics teaching and learning.

their beliefs about teaching and learning mathematics. Figure 3 displays a model explaining why these changes occur among preservice teachers participating in this study.

In this carefully designed enjoyable learning environment, preservice teachers are aesthetically engaged. During this intervention activity, preservice teachers' improvement of engagement in mathematics demonstrates three distinct levels: (a) In the beginning, their original interests to and previous joyful experience from music as well as their curiosity toward the relationship between music and mathematics engage them to participate in this mathematics lesson; (b) The pleasant experiences of drawing colorful pictures using crayons as a method to create music and to play their own work immediately on a digital piano further enhance their engagement; and then (c) Through this engagement, they are enabled to solve closely related mathematical problem-solving tasks by analyzing their own musical pieces.

During the same period of time that preservice teachers enhance their engagement in mathematics, their attitude and confidence toward mathematics teaching and learning also improves. During the mathematics lesson, the preservice teachers experience the power of mathematics in an aesthetic creation as mathematical knowledge is used to organize and arrange musical elements such as pitches and rhythms. The harmonic and powerful sound effects appear through their perceived and excited feeling increasing their positive attitude. Furthermore, when completing the activities during the intervention activity, preservice teachers not only feel a cheerful sense of accomplishment when completing the mathematical tasks but also receive an extra reward by enjoying their own composition works accompanied by the digital piano. This experience might be one of the reasons that preservice teachers' positive attitudes increases. During the whole process of using mathematics to create music, playing music, and using mathematics' knowledge to engage in mathematical tasks constructed from music of their own, participants in this study have enough freedom to create music and solve contextually meaningful mathematical problems while their confidence improves. They experience learning and flexibly use mathematics in a joyful environment without painful experiences. They feel that it is fairly easy to teach mathematics by integrating music. Thus, their confidence is enhanced while their anxiety toward mathematics decreases. Moreover, during the sharing of musical works while discussing mathematical tasks, classmates reveal and recognize each other's potential abilities. A strong sense of participants' personal discovery journeys emerges as they construct and explore meanings through their own works; thus, their attitude and confidence are further enhanced.

The change in preservice teachers' beliefs is followed by their improvement of engagement, attitudes, and confidence toward mathematics teaching and learning. Their experiences during this intervention activity helps them understand that there are rich connections between mathematics and music, and that it is possible to create a joyful mathematics learning environment by integrating music into mathematics lessons. Moreover, this activity allows preservice teachers to become aware that the process of music

creation does not only depend on intuition; mathematics also functions importantly in the composition process. Finally, from the class discussion about how to apply music into mathematics teaching, more methods and topics to teach mathematics content with music are revealed, and their beliefs are further changed; meanwhile, their confidence is further strengthened.

Understanding in Teaching Mathematics Connected With Music

The change in preservice teachers' answers on the two open-ended questions from pretest to posttest is also evidence to demonstrate how preservice teachers in this study change their belief and expand their knowledge toward mathematics teaching and learning. From the results, we find that not only the themes of relationship between music and mathematics as well as such integrated lesson topics but also the response rates are considerably increased. This demonstrates that preservice teachers not only identify and construct more connections between mathematics and music but also generate more lesson themes teaching mathematics integrated with music. This might be explained by the intervention activity that provided preservice teachers with successful and effective examples of mathematics–music-integration activities. To some extent, the intervention activity enlarges preservice teachers' visions of both pedagogical knowledge and pedagogical content knowledge about teaching mathematics integrated with music. This mathematics–music-integrated activity provides and inspires preservice teachers' ways of teaching and learning mathematics. In this activity, preservice teachers experience the whole process of music production from introducing theories and rules, to composing based on rules, to playing and communicating music works.

During this composition process, several links between mathematics and music focus on multiple mathematical content topics by (a) employing a mathematical formula to compose music; (b) exploring the combination of chords in music; (c) investigating the probability of different songs that can be composed based on this formula; (d) investigating the probability of different songs that can be composed by a combination of different music pieces; (f) trying to propose mathematics problem-solving questions based on this activity; and (g) discussing other relationships between music and mathematics. At the beginning, preservice teachers experience the feeling of being a learner in trying these mathematics–music-integrated activities and solving mathematics problems. They then need to transition to the role of a teacher in reflecting on these activities and problems. This might be one explanation for why the preservice teachers who participated in this study change perceptions and expand their knowledge toward the relationship between mathematics and music and the lesson themes that can be taught connected to music. Unlike those preservice teachers' previous perceptions that mathematics and music had few relationships or just superficial relationships, such as counting beats or rhythms or singing mathematics concepts (Rogers, 2004), after this activity's intervention as the results summarized in Tables 2 and 3 show, most preservice teachers' perceptions and knowledge toward music, as well as mathematics, increase to higher-order relationships that combine more complex mathematics with more insightful music knowledge. After the intervention, as the results show, preservice teachers could offer a variety of mathematics topics, which can be taught through similar music-related activities (e.g., statistical graphs, basic operations, fractions, ratio, percentage, and decimal numbers).

Conclusion and Educational Implication

In this study, we have presented the effects of a mathematics activity integrated with music composition. According to the results, this explorative study demonstrates that a mathematics lesson integrated with music has positive effects on preservice teachers' attitude, beliefs, engagement, and confidence toward mathematical learning and teaching.

Teaching mathematics integrated with other subjects can improve students' knowledge in both areas (NCTM, 2000): "Students . . . should have frequent experiences with problems that connect to real-world experiences, that interest, challenge, and engage them in thinking about important mathematics" (p. 182). Teachers should take advantage of the opportunities that music offers to help all students learn mathematics in challenging and enjoyable ways (Johnson & Edelson, 2003). We believe that by connecting arts or music into mathematics teaching and learning, preservice teachers may have more opportunities to change their beliefs about and attitudes toward mathematics. By designing appropriate music integrated into mathematics lessons, students can understand, analyze, and interpret mathematics through different routes. This strategy allows students to present and understand

mathematics in alternative ways, especially for those who have a high level of musical-rhythmic intelligence. To achieve this goal, lessons or curriculum tailored to the needs of specific children may be designed and employed (Gardner, 1983). This exploration study, in turn, could serve to broaden and deepen educators' understanding of different ways students experience their learning and contribute to the creation of successful learning environments where more students can be engaged. The findings from this study invite further longitudinal research on other types of mathematics lessons using different links from music and mathematics and focusing on different mathematical content areas at various grade levels, concentrating not only on attitude and beliefs toward mathematics but also on mathematics achievement. Also, it is important to note the involvement of technology support necessary in this kind of integration so that every mathematics teacher can teach similar music–mathematics-integration lessons without intensive learning of music knowledge and skills.

Limitations were also noted in this study. First, the intervention period was short; thus, further changes in preservice teachers' attitude and belief in their later college years as well as in their future teaching is unknown. Second, the sample was fairly small, and the findings may not be generalized to other preservice teachers who study at other universities. However, even with all these limitations, this intervention study provided an opportunity to observe the connection between music and mathematics. We do not suggest that the intervention activities that integrated music into mathematics described in this study are a prototype for all classroom activities related to mathematics. We argue that the development of mathematical understanding, beliefs, and attitudes should not emanate from a single curriculum but should permeate the curricula with content other than mathematics, such as music.

We are not suggesting that preservice teachers should study an inventory of teaching all mathematics content with connections, especially, with music. However, preservice teachers should understand that mathematics is connected with other subjects outside of mathematics and can be taught by integrating other content. Thus, teachers' pedagogical content knowledge of how to teach students mathematics with sense-making, especially linked with arts, might provide an alterative way to design and teach an effective lesson. We suggest that teacher education programs familiarize preservice teachers with various connections—the connection within and out of mathematics contents.

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Keywords: Mathematics; music; connection; attitude; beliefs; intervention.

Piaget's Logic of Meanings: Still Relevant Today

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In his last book, Toward a Logic of Meanings *(Piaget & Garcia, 1991), Jean Piaget describes how thought can be categorized into a form of propositional logic, a logic of meanings. The intent of this article is to offer this analysis by Piaget as a means to understand the language and teaching of science. Using binary propositions, conjunctions, and disjunctions, a table of binary operations is used to analyze the structure of statements about conclusions drawn from observations of science phenomena. Two examples from science content illustrate how the logic of binary propositions is used to symbolize typical reasoning of secondary-school science students. The content areas are the period of a pendulum and the Archimedes' Principle, which were chosen based on observations in secondary science classrooms. The analyses of the student responses in these two observations demonstrate the commonalities of arguments used by students of science as they try to make sense of observations. The analysis of students' reasoning, demonstrates that Piaget's logic of meanings is a useful and relevant tool for science educators' understanding of the syntactical aspects of pedagogical content knowledge.*

> "I know the crowd will be cheering for Melanie (Oudin), but that doesn't mean that they are against me" (Caroline Wozniacki, Danish tennis player, quoted before the 2009 U.S. Open Women's Tennis Quarterfinal Match against Melanie Oudin of the United States).

At the U.S. Open Tennis Tournament in early September 2009, Caroline Wozniacki of Denmark was interviewed before her match with Melanie Oudin of the United States. The match was interesting itself because it featured two teenagers who, quite unexpectedly, had defeated ranked players to get this far in the tournament. However, the more interesting feature for this article is the quote that Ms. Wozniacki provided before the match. The structure of the quote is like the structure of arguments made by students to describe their interactions and thoughts when they are encountering scientific concepts and interpreting results of experimental situations.

Ms. Oudin and Ms. Wozniacki developed fan support during the previous matches because they upset older and more established tennis players who had won major tournaments in their careers. Now, Ms. Wozniacki was commenting that she knew that Ms. Oudin would receive the loud support of the fans in this match because they would be cheering for an American athlete at the U.S. Open. The statement implies that not cheering for Ms. Wozniacki (p = not cheering for Ms. Wozniacki) is not the same as being against Ms. Wozniacki (*not* q = not being against Ms. Wozniacki) and does not mean (does not imply) that the crowd is against her (p and *not* q = not cheering and not being against Ms. Wozniacki). For many, cheering implies being supportive for a player and being against the other, which Ms. Wozniacki denies in this situation. This statement demonstrates a high degree of reasoning (recognition of interacting factors), which Piaget termed as formal operational reasoning (Piaget & Inhelder, 1969). In *The Psychology of the Child*, Piaget introduced his famous stage theory of logical development to English-speaking audiences. At the time of his death in 1980, he was reformulating his theory with the help of Rolando Garcia, who was his coauthor of the book *Toward a Logic of Meanings* (Piaget & Garcia, 1991). Piaget's longtime collaborator Barbel Inhelder writes in the preface, "this volume attempts to recast operatory logic by extending it in two directions: toward the construction of a logic of meanings, from which operatory logic would naturally arise, and toward a new formulation of propositional logic, which has been tied too tightly to extensional logic" (Piaget & Garcia, 1991, p. vii).

Piaget's Logic of Meanings

Piaget outlined his analysis of the reasoning of children at the operational (concrete and formal) levels of reasoning in Chapter 5 of the book entitled *The Psychology of the Child* (Piaget & Inhelder, 1969) and in Chapter 17 of the book entitled *The Growth of Thinking from Childhood to Adolescence* (Inhelder & Piaget, 1958). What Piaget proposed was that children reasoned about logical/mathematical situations using structures that were like mathematical groupings and group structure, which are described by a form of a

propositional logic that focuses on the meaning (intentional aspects of reasoning) of action and practical logic used by children. Piaget (Piaget & Garcia, 1991) reformulated this propositional logic into a logic of meanings just before his death. Piaget interpreted children's interactions with materials and descriptions of their thinking from analyzing clinical interviews conducted by his colleagues, and him in terms of conjunctions, disjunctions, and binary operations. "These contingent and limited combinations between 'and' and 'or' may therefore take forms that are isomorphic to the 16 binary operations of a propositional logic (Piaget & Garcia, 1991, p. 27)." The 16 binary operations are formed using the symbols *p* and *q* to represent statements, properties, concepts, actions, etc. For example, if *p* represents a "duck" and *q* represents the phrase "in water," then *p* and *q* represent a "duck in water," with the word *and* being the conjunction of the two. The negations of these take the form *not p* is "not a duck," and *not q* is "not in water." The conjunction of these is *not p* and *not q*, which means "not a duck and not in water." This is referred to as conjunctive negation, which translates as neither/nor, which means neither a duck nor in water.

There are four different binary conjunctions of *p* and *q*: *p and q, p and not q, not p and q*, and *not p and not q*. These are used to represent logical reasoning describing the experiences of children in their efforts to verbalize their encounters with the content of science. Combining the binary statements with disjunction (*v* stands for or) in combinations of zero, one, two, three, or four binary statements generates a total of 16 binary operations, which combined with the inverse, identity, and reciprocal, and correlate operators describe the reasoning processes humans use for formal operational reasoning. For example, in terms of the binary operations, disjunction is *p* or *q* (*p v q*) = (*p* and *q*) *v* (*p* and *not q*) *v* (*not p and q*). In terms of "duck" and "in water," the statement reads: It is a duck or is in water or both. The three binary statements correspond to both (*p* and *q*), or either ([*p* and *not q*] *v* [*not p* and *q*]). The appendix lists the 16 binary operations. The disjunction operation is statement one on the appendix.

To return to Ms. Wozniacki's statement, "I know the crowd will be cheering for Melanie (and not cheering for me [*p*]), but that doesn't mean that they are against me (*not q = not against me*)." This, symbolically, is *p* and *not q*, which in the appendix is classified as statement six having the title nonimplication ("does not mean").

Science Content and the Logic of Meanings

Two classroom observations illustrate how Piaget's logic of meanings is used to analyze science student discourse. A common laboratory activity is to determine which variables affect the period (how long it takes for a swing) of a pendulum. It is an easy activity to set up, simple materials are used, data collection is quite easy, and it is displayed in a number of illustrative ways. A discussion of possible variables that affect the period of the pendulum generates a number of variables to consider: the length of the pendulum, the amount of mass suspended from the pendulum, the material from which the pendulum is made, and the angle from which the pendulum is dropped to start its motion. The use of scientific processes (observation, measurement, separation and control of variables, and analysis) are required to develop an answer to the problem of determining which variables affect the period of a pendulum. Given ideal conditions of zero friction and a small angle for the swing of the pendulum, only one of the variables listed has an effect on the period. As students work through this activity, they are expected to list observations, collect data, and draw conclusions.

As I worked with students engaged in this activity, I heard a number of statements that indicate the use of structures that fit the form of the binary operations. For example, changing the amount of mass suspended from the pendulum does not have an effect on its period. Before empirically testing this proposition, many students claim that the increasing the mass of the pendulum increases the period of the pendulum. Looking at the former statement, the change of the amount of mass (*p*) does not affect a change in the period (*not q*) of a pendulum, which in the appendix of binary operations is number six, the inverse of implication or nonimplication. On the other hand, students notice that changing the length of the pendulum does have an effect by changing the period. Translating this statement into binary operations, a change in the length of the pendulum (*p*) affects a change in the period (*q*). Conversely, if there is no change in length (*not p*), then there is no change in the period (*not q*). Taken together, the statement is (*p* and *q*) *v* (*not p* and *not q*). This is the equivalence, binary operation number nine, listed in the appendix. Piaget cautions that, "Propositional equivalence is neither an identity nor an equality but simply the assertion that two propositions are always both true or both false (Inhelder & Piaget, 1958, p. 300)." What does the

untrue statement that as mass increases (*p*) the period increases (*q*) demonstrate using the binary operations analysis? The students who believe this hold that the binary operations (*p* and *q*) *or* (*not p* and *not q*) are true, which is also binary operation number nine. Testing this statement empirically demonstrates that it is false. This analysis points out that false statements have the same form as true statements, and that in science, the truth of statements conforms to whether or not they are empirically demonstrated to be true.

Last spring, I observed a science intern at a local junior high school teach a physical science lesson. His students analyzed problems concerning Archimedes' Principle. The intern assigned some thought problems to his students from a popular book by Epstein (2002), *Thinking Physics: Practical Lessons in Critical Thinking*. One of the problems, titled *Water Bag*, is stated as follows:

> One cubic foot of seawater weighs about 64 lbs. Suppose you pour one cubic foot of seawater into a plastic baggie, tie the baggie closed with no air bubbles inside, attach a string to it, and lower it into the ocean. When the baggie of water is completely submerged, how much force do you have to exert on the string to hold it up? (a) Zero lb, (b) 32 lbs, (c) 64 lbs, (d) 128 lbs, and (e) You have to push it down because it tends to come up (Epstein, 2002, p. 173).

Students chose one of the five answers and explained how they arrived at that answer. Some of the students chose the correct answer, and only a few could apply Archimedes' Principle (the buoyant force on an object is equal to the weight of the liquid displaced by the object) as a justification for their answer. A few students talked about how an object placed in a liquid would displace an amount of the liquid equal to the object's own weight, which is not the case for objects denser than the liquid. Other students stated that the buoyant force of the seawater would be equal to the weight of water displaced. Because the densities of the seawater and the seawater in the baggie are the same, the baggie displaces an amount of seawater equal to its weight. Additionally, the force of gravity pulling the seawater in the baggie down and the buoyant force of the seawater pushing the baggie up are equal and are in opposite directions, and therefore, require no additional force to hold it up. The logical/mathematical reasoning in this case requires a chain of connections that only a few junior high school students can manage.

Let us examine one piece of this explanation: the buoyant force of the seawater is the same as the weight (force of gravity) of the seawater in the baggie and in opposite directions, consequently requiring no additional force to hold it up. Symbolically, a change in the amount of seawater displaced (*p*) by an object produces a change in the buoyant force (*q*) on the object, and no change in the amount of seawater displaced (*not p*) produces no change in the buoyant force (*not q*). In terms of the binary operations, Archimedes' Principle is represented by number nine on the appendix. Consider a closer look at another statement: an object placed in a liquid displaces an amount of the liquid equal to the object's own weight, which is further qualified by adding that it is a floating object. If this statement is analyzed, it has the same form as the statement of Archimedes' Principle and is represented by statement number nine. As in the pendulum example, binary operations can be used to analyze the form of statements made about scientific relationships that are shown to be empirically untrue or need qualification. It was interesting and informative to watch the students of this intern struggle with the complex interrelationships implied by Archimedes' Principle, as well as the added complication of the effect of density on objects sinking or floating.

Application of Logic of Meanings

The above examples demonstrate that the logic of meanings that Piaget formulated can be used to analyze the reasoning of students about scientific principles. The symbologies of the binary operations in these examples points to the same structure for statements of scientific relationships, i.e., both are equivalence relationships: the length of a pendulum is related to the period, and the buoyant force is equal to the weight of the displaced water. Many of the phenomena studied in science classrooms fall into the category of equivalence relationships. Knowing this and recognizing the use of the logic entailed help teachers to recognize not only correct structures of reasoning but maybe more importantly recognize faulty reasoning or the application of scientific misconceptions. Teachers are then able to provide more effective instruction and activities to help students improve their understanding based on deeper knowledge of how students derive meaning from what they are learning.

Students may have logically consistent reasoning, but as in the example with the bag of seawater, the students are not able to recognize the principles that apply in this situation. Teachers would be able to help students by referring them to the empirical data that pointed the insufficiency of students' analyses. Teachers, who understood the way that propositional logic underpinned the arguments that students used, both the empirically supported and unsupported, would be able to provide counter examples that challenge students thinking and reasoning, which can lead to conceptual change. In the water bag situation, a counter example is to drop an object, which is denser than water, into a container of water, then measure the amount of water displaced by the object. The weight of the object will be greater than the weight of the water displaced. The students would have to determine how Archimedes' Principle fits with this observation.

Conclusion

The logic of meanings described by Piaget in his last book (Piaget & Garcia, 1991) provides a tool for classroom teachers to look more deeply at the science discourse of their students. I believe that this in-depth look enables teachers to diagnose and provide better educational opportunities for their students. Such an analysis of student understanding, also, uncovers the common aspects of scientific argumentation. Where will teachers learn how to do such analysis of student discourse? Ideally, science educators would be able to provide the experiences that enable teachers to use the tool of the logic of meanings to inform their teaching practice. Being able to recognize the syntactic structures of the discipline is an important skill for science teachers and a component of pedagogical content knowledge (Grossman, Wilson, & Shulman, 1989). Twenty-nine years after Piaget's death, his work on a logic of meanings still has relevance for the science classroom and provides an additional tool for the analysis of student discourse.

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Appendix

Sixteen Binary Operations of Formal Operational Reasoning

1. Disjunction ($p \vee q$) = (p *and* q) v (p *and not* q) v (*not* p *and* q): either or both
2. Inverse, conjunctive negation (*not* p *and not* q): neither/nor
3. Conjunction (p *and* q): both
4. Incompatibility, inverse of conjunction (p/q) = (p *and not* q) v (*not* p *and* q) v (*not* p *and not* q)
5. Implication: p *implies* q = (p *and* q) v (*not* p *and* q) v (*not* p *and not* q)
6. Inverse of implication, nonimplication: (p *and not* q)
7. Converse implication: q *implies* p = (p *and* q) v (p *and not* q) v (*not* p *and not* q)
8. Inverse of converse implication: (*not* p *and* q)
9. Equivalence ($p = q$) = (p *and* q) v (*not* p *and not* q)
10. Inverse of equivalence, reciprocal exclusion: (p *vv* q) = (p *and not* q) v (*not* p *and* q)
11. Independence of p in relation to q: p (q) = (p *and* q) v (p *and not* q)
12. Inverse of independence of p in relation to q (which is also its reciprocal): *not* p (q) = (*not* p *and* q) v (*not* p *and not* q)
13. Independence of q in relation to p: q (p) = (p *and* q) v (*not* p *and* q)
14. Inverse of independence of q in relation to p (which is also its reciprocal: *not* q (p) = (p *and not* q) v (*not* p *and not* q)
15. Complete affirmation or tautology: (p * q) = (p *and* q) v (p *and not* q) v (*not* p *and* q) v (*not* p *and not* q)
16. It is inverse, negation, or contradiction (0): An assertion that there is an effect and no effect at the same time.

PROBLEMS section

Ted Eisenberg, *Section Editor*

This section of the Journal offers readers an opportunity to exchange interesting mathematical problems and solutions. Please send them to Ted Eisenberg, Department of Mathematics, Ben-Gurion University, Beer-Sheva, Israel or fax to: 972-86-477-648. Questions concerning proposals and/or solutions can be sent e-mail to eisenbt@013.net. Solutions to previously stated problems can be seen at http://ssmj.tamu.edu.

Solutions to the problems stated in this issue should be posted before October 15, 2011

• **5164:** *Proposed by Kenneth Korbin, New York, NY*

A triangle has integer length sides (a, b, c) such that $(a - b) = (b - c)$. Find the dimensions of the triangle if the in-radius $r = \sqrt{13}$.

• **5165:** *Proposed by Thomas Moore, Bridgewater, MA*

Dedicated to Dr. Thomas Koshy, friend, colleague, and fellow Fibonacci enthusiast

Let $\sigma(n)$ denote the sum of all the different divisors of the posotive integer n. Then n is perfect, deficient, or abundant according as $\sigma(n) = 2n$, $\sigma(n) < 2n$, or $\sigma(n) > 2n$. For example, 1 and all primes are deficient; 6 is perfect, and 12 is abundant. Find infinitely many integers that are not the product of two deficient numbers.

• **5166:** *Proposed by José Luis Díaz-Barrero, Barcelona, Spain*

Let a, b, c be lengths of the sides of a triangle ABC. Prove that

$$\left(3^{a+b}+\frac{c}{b}3^{-b}\right)\left(3^{b+c}+\frac{a}{c}3^{-c}\right)\left(3^{c+a}+\frac{b}{a}3^{-a}\right)\geq 8.$$

• **5167:** *Paolo Perfetti, Department of Mathematics, University "Tor Vergata," Rome, Italy*

Find the maximum of the real valued function

$$f(x, y) = x^4 - 2x^3 - 6x^2y^2 + 6xy^2 + y^4$$

defined on the set $D = \{(x, y) \in \Re^2 : x^2 + 3y^2 \leq 1\}$.

• **5168:** *Proposed by G. C. Greubel, Newport News, VA*

Find the value of a_n in the series

$$\frac{7t+2t^2}{1-36t+4t^2} = a_0 + \frac{a_1}{t} + \frac{a_2}{t^2} + \cdots + \frac{a_n}{t^n} + \cdots.$$

• **5169:** *Proposed by Ovidiu Furdui, Cluj, Romania*

Let $n \geq 1$ be an integer and let i be such that $1 \leq i \leq n$. Calculate:

$$\int_0^1 \cdots \int_0^1 \frac{x_i}{x_1 + x_2 + \cdots + x_n} \, dx_1 \cdots dx_n.$$

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Membership: At least one author of any feature article must be a member of the School Science and Mathematics Association at the time of acceptance of the article. The membership provides a one-year subscription to the journal.

Manuscript preparation:

All manuscripts must be prepared according to the 5th Edition of the Publication Manual of the American Psychological Association, typed double-spaced using a 12-point or larger font, and printed on 8 1/2- by 11-inch paper. Manuscripts should be limited to 25 pages, excluding figures, tables, and appendices. **Submissions that are not APA style or exceed the length limitation will be returned.**

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Design and methodology
Analyses of data
Conclusions based on results
Results related to professional practice and literature
Enough information to enable replication (quantitative)

SCHOOL SCIENCE AND MATHEMATICS

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LETTER FROM the editor

Dear *School Science and Mathematics* (SSM) journal readers:

It is with great enthusiasm that I have assumed the editorship of *School Science and Mathematics*. It is my hope that my co-editor Dr. Shelly S. Harkness and I will build upon the many years of excellent work that has been completed by previous editorial teams and continue to publish cutting-edge work in science, technology, engineering, and mathematics education.

In mid-May 2011, we took over as the new editorial team of *SSM* Journal, and we quickly learned that there was an abundance of high-quality manuscripts in the pipeline of the journal prior to assuming our leadership. In fact, we were given a backlog of nearly two years of articles waiting to be published. As a result, we took immediate action and presented this to the School Science and Mathematics Association (SSMA) Board of Directors who agreed to fund the printing of additional pages during the 2012 calendar year to accommodate the backlog. In addition, I worked with our publisher, Wiley-Blackwell, to develop and implement space-saving changes for the journal that will yield enough space for an additional article per issue.

It has become very clear to the editors, as well as the SSMA Board, that the publication guidelines must be strictly followed to ensure timely production of journal issues. Therefore, we have sent requests to authors who were outside of the 25-page limit (text and references) to revise their articles. There is also now a limit of five pages on the number of total tables/figures/appendices—including the stipulation that each table/figure/appendix must fit on one page. New manuscripts that have been submitted since May have been rejected without review if these page limits were not followed.

In addition to page-count concerns, there are also many papers that have not followed the American Psychological Association (APA) format. At this time, all manuscripts that do not follow APA sixth edition will be returned to the author without review. We are now asking for copyright transfer forms to be submitted with the manuscript to streamline the process and meet our production deadlines. We believe that compliance with existing guidelines and the implementation of additional guidelines will decrease the time of publication.

Wiley-Blackwell has worked with us to create some exciting expansions to the SSM Journal. Beginning October 2012, the space in the journal will be reserved for publication of research articles only. We recognize that there are also very important works that warrant dissemination to our audience, and we have worked with Wiley-Blackwell to begin publishing content online in 2012. One new feature will be accompanying "research to practice" articles that will be paired with research manuscripts published in the journal. These will be three- to five-page pieces that translate research to practice posted on the *SSM* Journal website. We are seeking graduate students who are interested in being considered as prospective authors for the companion pieces, and we are developing a database of potential authors. Authors are invited to solicit their own graduate students to write their companion articles. Our office will forward companion pieces to the original author for review, prior to being posted on the website. If you are a graduate student interested in serving in this role, contact the *SSM* Journal editorial assistant, Stephanie Harrison, at harrisossmj@gmail.com for an application.

The *SSM* Journal "Problems" section will continue under our leadership. The solutions to the "Problems" will be posted on the SSMA website, along with many of the past problems/solutions for easy access at www.ssma.org the SSMA website.

As a final note, we have implemented the requirement that lead authors on articles submitted to the *SSM* Journal must be members of SSMA. The rationale is that the *SSM* Journal is published by SSMA and publication in the journal is a benefit of membership. The membership fee continues to be very reasonable and all members receive hard copies of all issues of the journal as well as access to the journal website that houses over 100 years' worth of electronic copies of the journal.

We are extremely pleased to lead the *SSM* Journal and look forward to working with many of you over the next five years!

Sincerely,

Carla C. Johnson
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A Comparison of Concrete and Virtual Manipulative Use in Third- and Fourth-Grade Mathematics

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Ellen M. Hamm
Canisius College

The primary purpose of this classroom experiment was to examine the effectiveness of concrete (hands-on) manipulatives as compared with virtual (computer-based) manipulatives on student review of fraction concepts in third grade and introduction of symmetry concepts in fourth grade. A pretest–posttest design was employed with a sample of 91 third-grade students and 54 fourth-grade students who were randomly assigned to complete a lesson using either concrete or virtual manipulatives. Students used a variety of manipulative materials during the lessons. Results of the posttest suggest that student learning was unchanged by lesson condition.

Manipulatives have been widely touted as valuable mathematical tools that provide experiential learning through concrete objects. This is derived, in part, from the theories of Piaget (1952, 1970), Bruner (1966, 1986), and Skemp (1987) who all agreed that concept development follows a progression from physical objects (or mathematical tools) to representational forms and abstract thought. "Students' mental images and abstract ideas are based on their experiences. Hence, students who see and manipulate a variety of objects have clearer mental images and can represent abstract ideas more completely than those whose experiences are meager" (Kennedy, 1986, p. 6).

Most people familiar with mathematical manipulatives relate to objects such as geoboards, bean sticks, Cuisenaire rods, and tangrams. However, innovations in technology have enabled the useful properties of concrete manipulatives and unique capabilities of computer technology to merge and create a new class of manipulatives—virtual or computer-based manipulatives. "A virtual manipulative is best defined as an interactive, Web-based visual representation of a dynamic object that presents opportunities for constructing mathematical knowledge" (Moyer, Bolyard, & Spikell, 2002, p. 372).

The National Council of Teachers of Mathematics (NCTM, 1989) identifies an important role for computers as tools to assist students not only with the exploration and discovery of mathematical concepts but also with the transition from concrete experience to abstract mathematical ideas. Although concrete manipulatives are considered physical objects and the link from physical object to abstract thought may be apparent with traditional manipulatives, this concept appears more difficult to support with virtual manipulatives. The role of virtual manipulatives in teaching mathematics shows a promise; however, little empirical evidence exists to support the use of computer-based manipulatives over traditional manipulatives in the classroom.

Objectives and Purpose

The purpose of this classroom experiment was to compare the effects of virtual and concrete manipulatives on student mathematical understanding of fractions and symmetry. Mathematical understanding of fractions and symmetry was defined as a score on teacher/researcher-made pretest and posttest. Potential benefits of the study include (a) increasing understanding of the educational impact of different teaching methods for mathematics, (b) providing educators with direction for use of manipulatives, both virtual and concrete, and (c) providing a model for studying the effect of technology on student learning.

Concrete manipulatives appear to be accepted by math educators and the benefits of concrete manipulatives have been supported in research (Clements, 1999; Suydam, 1985; Suydam & Higgins, 1977). According to Sowell (1989), students engaged in long-term use of concrete manipulatives at the early elementary level outperform students who do not use manipulatives. In a case of manipulative use for middle school students with mathematical disabilities, Butler, Miller, Crehan, Babbitt, and Pierce (2003) compared 26 students using concrete manipulatives with a control group of 24 students using representational drawings. Results of this study suggest that both groups showed overall improvement in their understanding of fraction equivalency from pretest to posttest with students in the concrete manipulative group demonstrating overall higher mean scores as compared with the control.

Other studies have focused on the relationship of students' achievement levels and teachers' experience in using manipulatives. Raphael and Wahlstrom (1989) found that teachers, reporting use of a variety of instructional aides, were able to cover more content, and the use of these aids was found to strongly relate to student achievement in topics such as geometry, ratio, proportion, and percent.

Although research generally supports concrete manipulative use, it is not a guaranteed success. Ball (1992) argues that "although kinesthetic experience can enhance perception and thinking, understanding does not travel through the finger and up the arm" (p. 47). Moyer (2001) found that in middle grades, if teachers were not strong in the mathematical concepts, using manipulatives was merely a diversion in their classrooms.

Research on the benefits of computer or virtual manipulatives is just beginning to be noted in the literature. Results of available research on virtual manipulatives offer potentially beneficial uses of technology in the mathematics classroom. For example, a variety of studies in which computer manipulatives were examined for their ability to support student learning in mathematics suggest positive results in student achievement and attitude (Char, 1989; Clements & Battista, 1989; Kieran & Hillel, 1990; Steen, Brooks, & Lyon, 2006; Thompson, 1992). More recently, results have indicated statistical significance when using virtual manipulatives to learn about fractions in a third-grade class (Reimer & Moyer, 2005), and have allowed discovery learning through experimentation and hypothesis testing, encouraged students to see mathematical relationships, connected iconic and symbolic modes of representation explicitly, and prevented common error patterns in fraction addition (Suh, Moyer, & Heo, 2005).

Research comparing on-computer with off-computer manipulative use in the classroom is limited and is difficult to generalize across math concepts and grade levels. Ainsa (1999) examined the use of virtual manipulatives to introduce numerical problem solving in early childhood classrooms. A group of 101 children were exposed to both hands-on and virtual manipulatives. Observations of their response, enthusiasm, and learning were recorded. Results suggest that children responded favorably to both types of manipulatives, and the author suggested combining virtual and hands-on manipulatives. In a study comparing manipulative use by fourth- and fifth-grade students, Olkun (2003) reported that both virtual and concrete manipulative groups improved significantly over the control group (no manipulatives), although the computer group improved slightly more. Results indicated that the fourth graders gained more with concrete (off-computer), whereas the fifth graders benefited more from the virtual manipulative.

Furthermore, investigators examined the impact of virtual manipulatives on geometry instruction and learning in a pretest–posttest design with 31 first graders randomly assigned to use either virtual manipulatives or traditional physical manipulatives, and worksheets. Researchers concluded that although both groups improved in geometry knowledge from pretest to posttest, the point differences between the groups were not statistically significant (Steen et al., 2006). As evidenced by an examination of current literature, the choice between computer and concrete manipulatives in mathematics education is not very clear.

Method

Participants

Participants of the current study were third- and fourth-grade students from a large, suburban, elementary school in Western New York. Teachers were informed that the researchers were examining the effect of virtual and concrete manipulatives on the math knowledge of elementary school students, with a nondirectional hypothesis. Parents were sent an informational letter and asked to return a signed consent for their child to participate.

Grade Three. Of the available 102 third-grade students, 91 returned signed consent forms and fully participated in the study. Participants from grade three were in four different classrooms with four different classroom teachers. Within each classroom, participants were randomly assigned to one of the two treatment conditions: virtual manipulatives or concrete manipulatives. A total of 42 students (23 males and 19 females) participated by using virtual fraction manipulatives, whereas a total of 49 students (28 males and 21 females) participated by using concrete manipulatives. All teachers were reviewing the fraction unit (primarily equivalent fractions, ordering fractions, and mixed numbers) at the time of the study.

Grade Four. The second group was comprised of 54 fourth-grade students with 100% consenting to participation. The students were from three different classrooms, but all had the same mathematics teacher. In this group, one whole class (18 students: 10 males and 8 females) was assigned to virtual manipulatives, one whole class (20 students: 10 male and 10 female) was assigned to concrete manipulatives, and the third class was divided between the virtual manipulative treatment and the concrete manipulative treatment (7 virtual: 4 male and 3 female, and 9 concrete: 5 male and 4 female). At the time of the study, fourth graders were beginning the topic of symmetry.

Procedures

The following section describes the procedures used for both grade levels. Teacher input was solicited throughout the experiment, and researchers and classroom teachers were present in the classroom at all times during the lesson. A variety of manipulative materials were used for

each treatment group in an effort to avoid a critique of a specific computer program, Web site, or manipulative material.

A pretest, treatment, and posttest quasi-experimental design was used for each group. Pretests were administered by classroom teachers, scored by a research assistant and checked by the researchers to ensure accuracy.

Grade Three. For third-grade participants, results of the pretest were taken into account as students were assigned to virtual and concrete subgroups. Subjects were divided to ensure equal ability grouping in each condition (i.e., an equal number of the top-, middle-, and low-achieving students). Pairs of students were randomly formed from these subgroups to work on the various tasks. The virtual manipulative group was directed to two different Web sites: www.visualfractions.com, a tutorial that models fractions with number lines or fraction circles; and nlvm.usu.edu, a site linked to NCTM standards from which students explored renaming fractions using fraction squares or fraction circles. Both sites provided immediate feedback as students worked through problems. Although not utilized by the students for this class lesson, both sites contained tutorials, games, and links to additional math resources, which could be used to reinforce skills. In addition to the Web sites, the fraction bars activity from the software program Hands-on Math (Ventura, 2001) was also used.

The concrete manipulative group completed similar fraction activities using hands-on fraction circles and fraction bars. Students were directed to specific activities as the researchers and classroom teacher walked around the room to give direction and feedback. All students were responsible for completing the same worksheet based on their work with manipulatives; however, the worksheets were not graded and the students were aware that the worksheets were for the in-class activity only. Each group had approximately 20 minutes per activity for a total class time of one hour. The posttest was then administered by the classroom teacher the following day, again scored by a research assistant, and checked by the researchers.

Grade Four. Cluster sampling was used in the fourth-grade classes as they were randomly assigned by classroom to virtual or concrete manipulatives. Students within each classroom were randomly assigned to work in pairs. All students participated in the same introduction to symmetry. The virtual manipulative group was directed to two different Web sites to complete activities, whereas the concrete manipulative group worked on activities with the manipulative Mira. Web sites used were nlvm.usu.edu, where students explored the sketch pad to learn about reflection symmetry, and www.mathsnet.net, in which students explored transformations-reflections through a hit-the-target activity and a playing-with-reflections activity. Both groups worked on their respective activities for 60 minutes while completing a nongraded worksheet. Posttests were administered the following day by the classroom teacher, scored by a research assistant, and checked by the researchers.

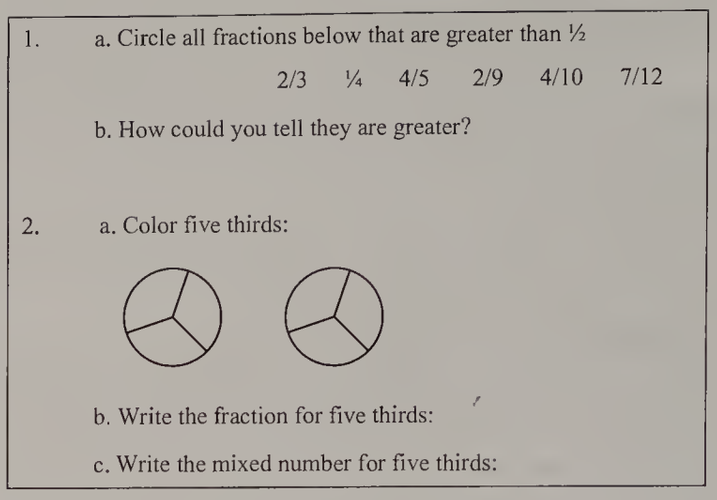
1. a. Circle all fractions below that are greater than ½
2/3 ¼ 4/5 2/9 4/10 7/12
b. How could you tell they are greater?
2. a. Color five thirds:
b. Write the fraction for five thirds:
c. Write the mixed number for five thirds:

Figure 1. Sample fraction questions from third grade.

Pretest and Posttest

For testing purposes, a researcher-made pretest and posttest was constructed to measure the students' knowledge in the math concepts of interest for each grade level. All questions were approved by the classroom teachers prior to testing. All pretests were presented by the classroom teacher the day prior to the lesson, and posttests were presented by the classroom teacher the day following the lesson. The fraction pretest and posttest consisted of 13 questions about fractions worth a total of 29 points. Examples of fraction questions can be found in Figure 1. Grade four participants were pretested and posttested on facts regarding symmetry with a test consisting of 10 questions related to line symmetry worth a total of 10 points. Question examples can be found in Figure 2.

Results

Grade-level data were analyzed separately due to the different mathematical constructs taught. Independent *t*-tests were run comparing mean scores for each grade with no significant difference noted. Mean pretest and posttest scores for third-grade students are reported in Table 1, whereas data for fourth-grade students are reported in Table 2.

Although both concrete and virtual third-grade manipulative groups showed improvement from pretest to

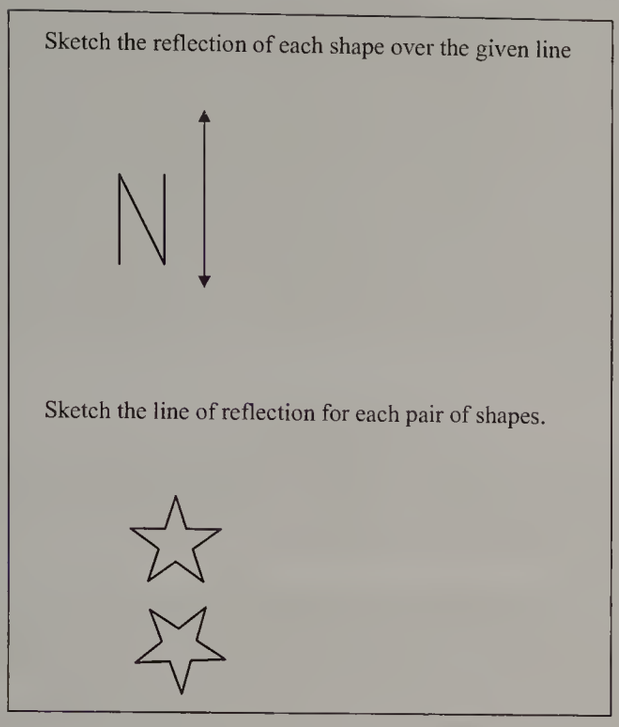

Figure 2. Sample symmetry questions from fourth grade.

Table 1
Mean Pretest and Posttest Scores for Third Grade (Fractions)

Group	*N*	Pretest		Posttest		Difference
		Mean	*SD*	Mean	*SD*	
Virtual	42	24.19	4.925	24.95	4.060	.76
Concrete	49	21.14	5.542	22.57	6.117	1.43

Note. Maximum score was 29.
SD = standard deviation.

Table 2
Mean Pretest and Posttest Scores for Fourth Grade (Symmetry)

Group	*N*	Pretest		Posttest		Difference
		Mean	*SD*	Mean	*SD*	
Virtual	29	6.07	1.889	6.66	1.696	.59
Concrete	35	4.94	2.114	7.34	2.55	2.40

Note. Maximum score was 10.
SD = standard deviation.

posttest, there was no statistically significant difference in the pretest and posttest scores of third graders' fraction knowledge. Actual point gains for the concrete manipulative group were slightly higher as compared with pretest and posttest gains for the virtual manipulative group.

Fourth-grade students also demonstrated posttest gains for both manipulative groups with the concrete group outperforming the virtual manipulative group in mean test scores; however, this difference was also not statistically significant.

Anecdotal Evidence

Grade four students were asked to record their opinion of the manipulative used. Students expressed excitement as they were informed of the use of manipulatives. Although initially, most students verbalized a desire for the virtual manipulatives, anecdotal comments from students support that fourth-grade students enjoyed using either manipulative. Comments from students who used the computer-based manipulatives included "we thought the website was fun because of changing the symmetry shapes" and "we thought the program was entertaining because it taught you how to use symmetry."

A sample comment from a student who used hands-on manipulatives included, "I thought it was really fun! It made the math class more exciting. It's basically a game. I hope we can do it again in middle school but I bet we won't. It was great!"

Discussion and Conclusions

Results suggest the use of either virtual or concrete manipulatives or a combination of both to reinforce math concepts. Although posttest results were not statistically significant for either third-grade students reviewing fractions or fourth-grade students learning symmetry, it is interesting to note that there were gains in the means for all groups from pretest to posttest. The gains for third-grade fractions were quite small, but this may be due to a ceiling effect on pretest as the students pretest scores were higher than expected. This was also a review unit for the third graders. Perhaps, more significant gains would have been realized if this was an introductory lesson on fractions.

Findings from the fourth-grade experiment contradict findings by Olkun (2003) who found the computer group improved slightly more than the concrete group. The fourth graders, who were just beginning a unit on symmetry, realized larger pretest–posttest gains when concrete manipulatives were employed. This gain may be a result of the concrete manipulative group's experience with the Mira for copying a reflected figure and drawing in the line of symmetry. This may have helped this group on the posttest when they had to draw figures and lines of symmetry. The virtual group, while doing similar activities on the computer, did not have the opportunity to use paper and pencil during the lesson, but were tested with a paper and pencil test. The effect coordinating teaching method to assessment method is a possible area for further exploration.

It appears that using virtual manipulatives was as effective as using concrete manipulatives for reviewing fraction concepts in this group of third-grade students and for introducing symmetry concepts in this group of fourth-grade students. This finding is consistent with the findings from Ainsa (1999) and Steen et al. (2006). Additionally, anecdotal evidence recorded from students during the sessions suggests that students were attracted to both types of manipulatives.

Moyer et al. (2002) suggest that on-computer manipulatives may be preferred because they are easier to manage (distribution and clean-up), readily available with an Internet connection or software, and older students view virtual manipulatives as more sophisticated than the concrete form. Another benefit of the virtual manipulatives is the immediate feedback available to the student. This may be especially important for independent class work or homework. The feedback can potentially allow the student to self-correct in a nonthreatening environment. An additional benefit of the virtual manipulatives used was that most are available free of charge on the World Wide Web and could be used by students with computers at home to reinforce concepts learned in the classroom.

One noted drawback to virtual manipulatives was the requirement for advanced planning for equipment and setup. The participating classrooms used laptop computers with wireless Internet. This equipment is not readily available in all schools. Besides equipment, time for setup of the virtual manipulatives was also a factor. Researchers spent time loading all computers with software and Web sites prior to class, but the concrete manipulatives were immediately accessible and could be set up by students. Additionally, technology problems such as low battery power and interrupted Internet service interfered with the lesson.

This research was intended as a pilot study to investigate the uses of concrete manipulatives and virtual manipulatives, and results are tentative based on a small sample, limited use of manipulatives, and limited time frame. The results may have been different if extended time was available to use the different types of materials. With these limitations in mind, it is suggested that educators use either or both types of manipulatives in the math class. Based on teacher reaction to the use of manipulatives in the classroom during this experiment, it is suggested that teacher education programs and school district in-service training focus on how to incorporate technology into teaching concepts. The classroom teachers participating in the study expressed great interest in using the virtual manipulatives; however, they were inexperienced in how to integrate this technology efficiently and effectively into classroom teaching.

Suggestions for further research include examining specific characteristics of virtual manipulatives and the usefulness for differentiating instruction using virtual manipulatives due to their inherent adaptability. Additionally, student and teacher perceptions of manipulative use should be explored as perceptions may impact student performance.

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A "Coprolitic Vision" for Earth Science Education

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James H. Wandersee
Louisiana State University

William Buckland (1784–1846) first identified and scientifically studied coprolites in the early 1820s. Although some of his contemporaries did not look favorably upon him or his research, Buckland's early experiments advanced paleoecology and taphonomy. Because our informal presentations with coprolites resulted in students' spirited reactions, we investigated whether coprolite introduction, accompanied with its history of science, had potential for meaningful learning in K-12 Earth Science classrooms. Practicing Earth Science teachers (N = 28) enrolled in an online paleontology course researched coprolites, identified potential student interest, and designed coprolite activities for their individual classrooms. Resulting projects were diverse and creative, and incorporated investigations into fossilization processes, paleoenvironments, food chains, and geologic time. In anonymous surveys, teachers indicated that their students' interest in coprolites is high. We propose inclusion of coprolites and their history in Earth Science classrooms as a portal to hook students' interest and as springboard to additional scientific topics.

Some students enter Earth Science classrooms as reluctant learners. Therefore, as instructors, our goals typically include the development and incorporation of effective methods to capture our students' attention and engage them in meaningful learning experiences. Our research in informal and formal science settings (Clary & Wandersee, 2008; Clary, Wandersee, & Carpinelli, 2008) demonstrated that both the history of science and the introduction of interesting fossils can pique the curiosity of students and transform them into interested learners. Could the unusual topic of coprolites (fossil feces), coupled with its interesting research history, provide an effective portal for Earth Science study in K-12 classrooms?

We previously observed that in classroom demonstrations and informal fossil presentations, students of all ages had noticeable reactions when coprolites were introduced. While some students were intrigued and responded positively, other students—particularly some elementary girls—responded to coprolites as "gross" and "disgusting." Nonetheless, even with off-putting reactions, the students' responses were enthusiastic.

Therefore, we investigated whether a more formal introduction of coprolites, which incorporated the history of coprolite science, could pique students' interest and serve as an effective springboard to scientific constructs in K-12 Earth Science classrooms. This research investigation proceeded through online paleontology courses composed of practicing teachers who taught an assortment of science courses at various grade levels.

History of Coprolites, History of Science in Science Classrooms, and Fossils in Science Classrooms

Coprolite Research: William Buckland and Origin of "Scientific" Excrement

Coprolite research has a fairly long history. As early as 1821, scientists were encountering fossilized excrement during their field explorations. The Reverend William Buckland (1784–1846; Figure 1) was one of the more colorful geologists during the Golden Age of Geology (1788–1840). Often referred to as the "first professor of geology" at Oxford University, Buckland was first appointed as a reader in mineralogy. In 1818, when a readership in geology was created at Oxford, Buckland was appointed to the position (Pemberton & Frey, 1991). In 1821, he encountered white-hued balls of bony material within the fossils of Kirkdale Cave in Yorkshire, England (Duffin, 2006; Rupke, 1983). Buckland named this material *album graecum* because of its color and hypothesized that it was the fossilized fecal remains of hyenas. In order to gather support for his hypothesis, Buckland inquired of the keeper of the Exeter Change menagerie whether the *album graecum* resembled modern hyenas' feces (Rupke). He investigated further by sending samples to chemist William Wollaston (1766–1828) for analysis. The high phosphate content of the *album graecum* supported Buckland's claim. In his deliberate and thorough investigation of the source of the white bony material, Buckland was one of the first scientists to engage in experimental paleontology—notably with feces (Duffin).

This research into *album graecum* was not an isolated incident. Buckland's range of research grew, along with

Figure 1. Engraving of the Reverend William Buckland DD, FRS in 1833. The original painting was done by Thomas Phillips, with engraving by Samuel Cousins. This archived document is held in Buckland's portrait prints at Oxford University Museum of Natural History.

Figure 2. This specimen drawer from William Buckland's personal paleontology collection (housed at the Oxford University Museum of Natural History) is filled entirely with coprolites. Although much of Buckland's coprolite collection was auctioned off, several drawers of coprolite specimens are still preserved in the Buckland collection.

his fossilized fecal collection (Figure 2). Buckland recognized the elongated "bezoar stones" from Lyme Regis as the probable fossilized feces of ichthyosaurs, extinct Mesozoic marine reptiles. Polished sections revealed remnants of bone and fish scales (Rupke, 1983), which Buckland recognized as representing the undigested portion of the ichthyosaur's meal. Some bezoar stones actually were found near the pelvic area within the fossils of nearly complete ichthyosaurs, leading Buckland to suspect that these future coprolites were not voided at the time of the animal's death. In order to test his hypothesis that the spiral structure represented the internal and external expression of the extinct reptiles' digestive system, Buckland used Roman cement and attempted to replicate these spiral structures with modern dogfish and shark intestines (Figure 3). Buckland reported this research in 1829 at a meeting of the Geological Society of London. It was here that Buckland first proposed the generic term "coprolite" to describe fossilized excrement (Folk, 1965). Although this research was not published until 1835 in the *Transactions of the Geological Society of London* (Buckland 1835), Buckland's interest in coprolites continued and his collection grew. Additional research and illustrations on coprolites were included in Buckland's 1836 Bridgewater Treatise

Figure 3. To test his hypothesis that bezoar stones were fossilized feces whose spiral structure replicated the intestinal tract of modern dogfish and sharks, Buckland experimented with Roman cement and modern fish intestines to produce similar structures (specimens held in the William Buckland collection, Oxford University Museum of Natural History).

(Buckland 1836). Buckland's intense investigations into the origin and preservation of coprolites marked an early attempt at paleoecology (Brook, 1993; Pemberton & Frey, 1991) as well as early taphonomy research (Boylan, 1997). Taphonomy, or the study of all the processes that affect fossilization between an organism's death and incorporation into the fossil record, was not "officially" introduced into paleontological studies until the 1940s.

The Historical "Culture of Coprolites"

The study of coprolites became popular in Buckland's time (Rupke, 1983), and many notable period figures were involved in coprolite collecting and analysis. John Stevens Henslow (1796–1861), Professor of Mineralogy at Cambridge University, corresponded with Buckland.[1] Henslow sought clarification on the categorization of one of his finds and discussed the possible coprolitic origin of phosphate. (Henslow wrote that he had "no evidence to throw against the idea of the phosphate of lime having been ± digested matter [not coprolite but coprolitic].") Physician and paleontologist Gideon Mantell (1790–1852) sent a fossil fish with an embedded coprolite to Buckland.[2] Also contained in Buckland's letters are correspondence from chemist William Prout (1785–1850) and possibly Jaegar, and Buckland's own miscellaneous notes on coprolites.[3]

Perhaps geologist Henry De la Beche (1796–1855), who later became the first director of the British Geological Survey, best summarized William Buckland's zealous interest in coprolites with a scientific caricature, "A Coprolitic Vision" (Figure 4). William Buckland is portrayed in his full academic regalia, rock hammer in hand, standing before a cave. The cave's formations are in the spiral shape of the ichthyosaur bezoar stones, and the animals of the cave—some of them are extinct organisms that have been brought to life by the artist—are all in the process of defecating. De la Beche was a personal friend of Buckland's, and it is likely that his scientific caricature was meant only as a humorous attempt to mock the subject of Buckland's research, as opposed to questioning the science behind the investigations (Clary, 2003; Clary & Wandersee, 2010; McCartney 1977; Rudwick, 1975).

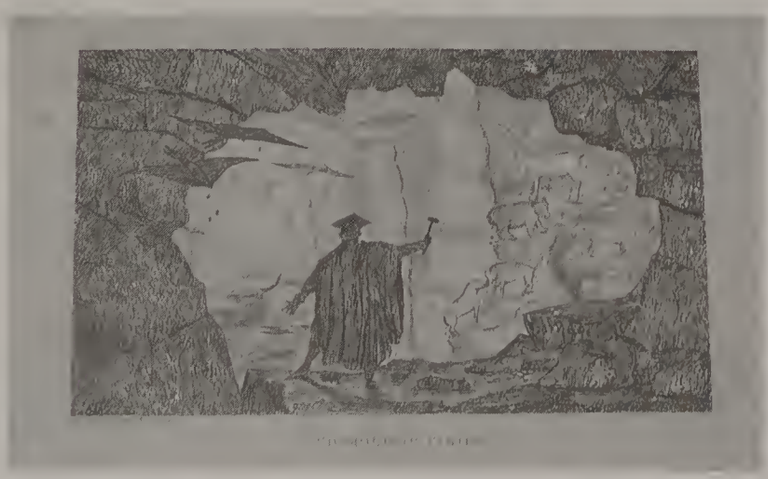

Figure 4. Henry De la Beche drew this scientific caricature as a humorous attempt to address Buckland's fascination with coprolites (modified from original print; the print is housed in the Geological prints, No. 1, Drawer 3, Number 33 of the Oxford University Museum of Natural History).

Although some period geologists viewed coprolite research as humorous, other geologists found the topic distasteful and had a less-than-positive opinion of William Buckland (Boylan, 1967; Frey, 1991; North, 1942; Pemberton & Frey, 1991; Rupke, 1983). While Buckland counted among his scientific admirers Georges Cuvier, De la Beche, Louis Agassiz, and William Conybeare, he did not find favor with Charles Lyell, Roderick Murchison, Charles Darwin, and Adam Sedgwick (Pemberton & Frey). Even in Buckland's day—before the polite rules of Victorian society—investigation into fossilized and modern feces was not considered by everyone to be a "proper" topic. Wollaston cautioned Buckland in 1822 that "though such matters may be instructive and therefore to a certain degree interesting, it may be as well for you and me not to have the reputation of too frequently and too minutely examining fecal products" (Rupke, p. 33).

The favor/disfavor conundrum of coprolites and Buckland is paralleled in *Duria antiquior*, or "Ancient Dorset." Henry De la Beche drew this aquarium graphic of Jurassic life as a fund-raiser for Mary Anning when she encountered financial difficulties. Although De la Beche's original watercolor and lithographic print portrayed a plesiosaur in the act of defecating, with the stuff of future coprolites resting on the seafloor (Figure 5), the "cleaned up" version painted by Robert Farron in the late 1840s has no visual representation of anything fecal[4] (Clary & Wandersee, 2010).

However, Buckland's pursuit of the crude and potentially distasteful is well documented. The Philpot Museum in Lyme Regis, England houses William Buckland's coprolite table (Figure 6). Cut and polished fish coprolites are inset to form the table's eating surface, and the modern viewer easily imagines the coarse humor that ensued when Buckland came to a gastronomic and coprolitic "full circle" by serving his guests' repast on fossilized excrement.

Coprolites may have represented a crude or distasteful topic to some of Buckland's contemporaries, but Buckland's experimental research was conducted with sound, scientific methods. Coprolites still form the basis of sound, modern paleontological research. Karen Chin, Glenna Dean, and Jim Mead investigate coprolites to uncover clues of past environments and extinct organisms. Chin's research is diverse, and she has reported on coprolites from herbivorous dinosaurs (Chin, 2007), as well as an extremely large theropod coprolite discovered in Canada (Chin, Tokaryk, Erickson, & Calk, 1998). Coprolites serve as valuable windows into ancient organisms, diets, and evolution.

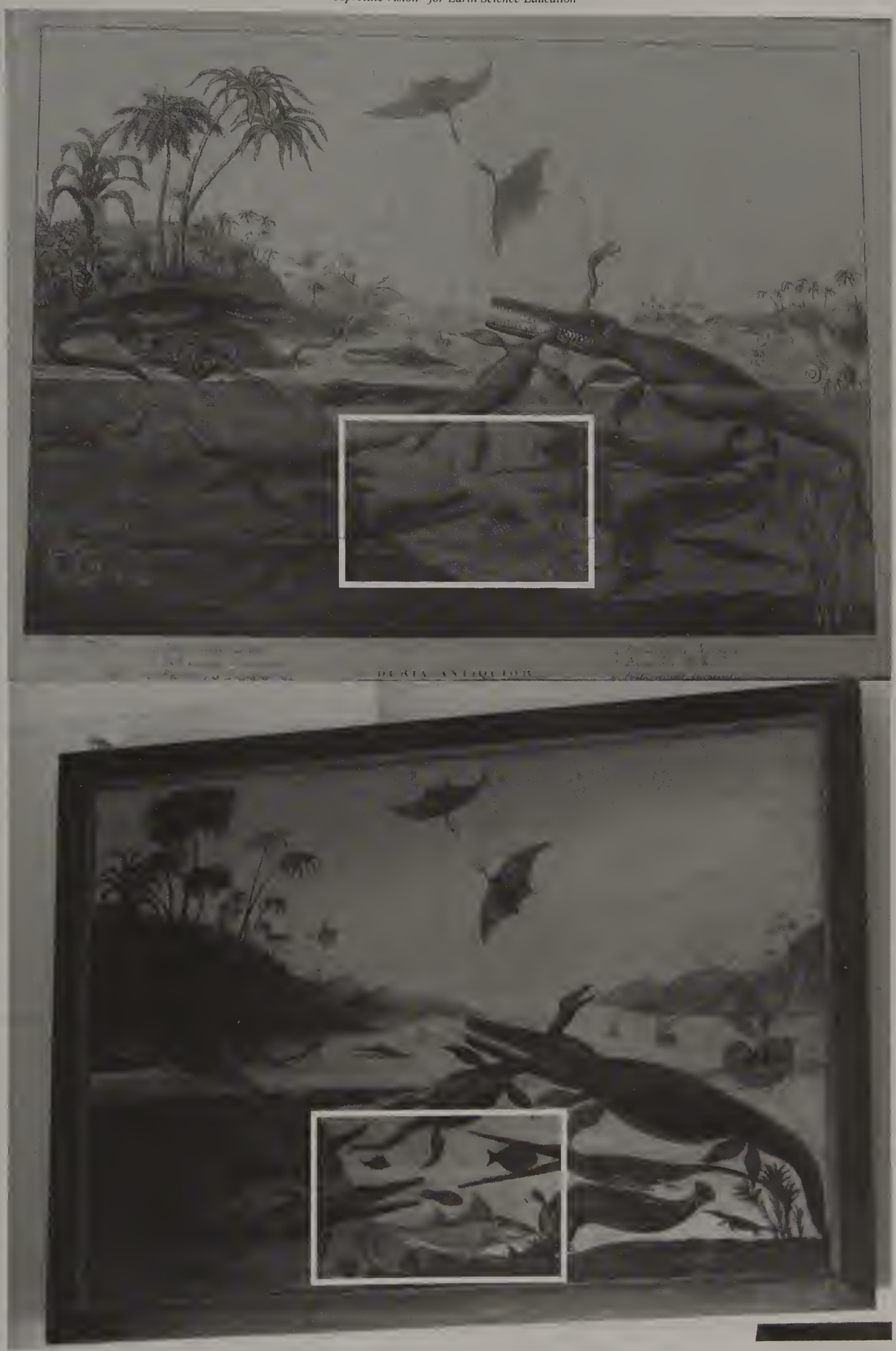

Figure 5. Henry De la Beche drew *Duria antiquior*, an original aquarium view graphic of Jurassic Dorset. This lithograph was produced from the original and sold to raise funds for Mary Anning. Note the plesiosaur defecating in the upper image. However, when Robert Farron painted a large oil copy of the graphic, lower photograph, the stuff of future coprolites was notably absent (*Duria antiquior* lithograph courtesy of the British Geological Survey).

Figure 6. William Buckland's table is made of cut and polished fish coprolites. It is housed in the Philpot Museum, Lyme Regis, England.

The Relevance of the History of Science in the Classroom

Not only is William Buckland's investigation into the excrement of extinct organisms inherently interesting, but research suggests that positive outcomes may result with the inclusion of this history in Earth Science classrooms. Although Earth Science has a marginal position in the majority of U.S. secondary schools today (Revolution in Earth and Space Science Education, 2001), geology was the popular science of the 1800s (Herring Davies, 2007), and many of the population were engaged in "geologizing." The incorporation of the history of science in the science classroom can serve as a "hook" for students to see science as an interesting endeavor, and connect science to the cultural, political, and social context in which it emerged (Matthews, 1994). The history and philosophy of science can serve to humanize the curriculum (Jenkins, 1989), and demonstrate how scientific knowledge is restructured and modified as new data and research materialize (Duschl, 1994). By exposing our students to the history and philosophy of science in our classrooms, instructors can confront student misconceptions of the linearity of scientific advancement and the streamlined perception of "final form" science (Duschl, 1990). The history of science reveals the personalities and inherent biases of scientists but importantly demonstrates that the scientific community ultimately triumphs through the correction of false claims and exposure of poor research (Clary et al., 2008). Educational research studies reported positive benefits with the incorporation of the history of science in science classrooms (Abd-El-Khalick & Lederman, 2000; de Housson & Kaminski, 2007).

Fossils in the Classroom and the Use of Marquee Fossils

Other research investigations demonstrated that interesting fossil specimens can serve as a portal through which teachers can integrate content across disciplines (Clary & Wandersee, 2008). Burr, Chiment, Allmon, and Rigby (2003) used an unidentified fossil to engage students as well as the public. A "marquee fossil" is defined as a fossil specimen that attracts attention and invites observation because of its unique and interesting characteristics. Marquee fossils tempt students into a deeper study of the curriculum and can serve as a gateway through which teachers can construct meaningful learning. Teachers reported that these fossils can be used in their classrooms to integrate biological processes of the once-living organisms and the environmental constraints of the ecosystem, as well as the organisms' paleoenvironments and the changes that Earth has experienced over geological time (Clary & Wandersee). Furthermore, marquee fossils may have historical importance by having links to famous scientists, bringing the history of science into a classroom.

Excrement in Informal Science Environments

Excrement and coprolites have served as successful topics in informal learning environments. Following the success of Lynch's (2001) children's book, *The Scoop on Poop*, a traveling museum exhibition of the same title premiered in 2006. The exhibit's designers did not just capitalize on the "ick" factor but instead focused on educational value. *The Scoop on Poop* invites visitors to explore the formation and characteristics of modern scat as well as fossilized coprolites. Chad Peeling, one of the developers, noted: "Our goal with the exhibit was to make people think, kids especially, about the science in all aspects in life and this thing that adults don't like to talk about" (Gresko, 2006). We investigated visitor reactions at *The Scoop on Poop* on its Mesa, Arizona tour in 2008 and observed adults, as well as children, engaged in a variety of interesting and interactive activities. Conversation abounded and focused primarily on fecal and coprolitic investigation, as opposed to strictly emotional commentaries.

The Scoop on Poop is not the first informal exhibit to capitalize on scat and coprolites. We visited a local museum-created excrement exhibit in Philadelphia in 2003, and an "All the Poop" exhibit toured Japan in 2001 (Gresko, 2006). A permanent Poop Museum actually resides in Japan. We propose that informal science educators have long recognized the intrinsic attraction that feces and coprolites have on audiences, even within "polite societies" where such topics are not usually discussed.

Methods

History of Life is a master's level paleontology course taught entirely online through a research university in southern United States. The class is composed primarily of practicing Earth Science teachers enrolled across the United States. A typical course is divided into 12 units, with three units combining to form a quarter. The assignments for each unit typically include a recorded video lecture, textbook and supplemental reading assignments, and a quiz, which serves as a formative assessment of low-point value. In each quarter, teachers are assigned homework exercises that characteristically include laboratory investigations, literature research, and classroom application activities. Individual fossil kits are mailed to the enrolled teachers and are utilized in various assignments. The course's available forums for communication include online discussion boards, chat rooms, and e-mail. History of Life is offered as a second-year elective to teachers within the master's program, and it may also be scheduled by teachers who have completed their master's degree and are now pursuing a "plus 30" degree certification. Therefore, all teachers who are enrolled in the course have familiarity with the online environment and the typical structure of the university's online classes.

Research Design

Several factors prompted our investigation of a formal introduction of coprolites and their history in K-12 Earth Science classrooms: (1) vivid—though varied—responses of students to coprolites during our informal rock and fossil presentations; (2) the benefits of the history of science in the science classroom as affirmed by numerous educational research studies; and (3) the potential for increased student interest with the use of unique marquee fossil specimens (including those tied to historical figures) as portals for interdisciplinary scientific investigation. As a result, we developed a coprolite assignment for the practicing teachers enrolled in the History of Life course as part of a quarterly homework exercise. Not only was the coprolite topic directly relevant to our course curriculum, but the teachers could identify the methods by which coprolites might be incorporated in their individual K-12 classrooms and whether this topic would be well received by their students.

The Paleo-Waste Assignment

The Paleo-Waste assignment consisted of two basic components: research/investigation and classroom/application. The research component required in-depth investigation into the scientific value of coprolites, including the paleoenvironmental information contained in coprolites, the composition of coprolites, a perpetrator's characteristics as discerned from its waste, and identification of perpetrators. A reference list was required.

The second part of the assignment mandated that the practicing Earth Science teachers design coprolite activities for their own classrooms, injecting the history of coprolite research in their classroom introduction to the topic. Teachers were required to describe their current classroom, including the number of students in each class, grade level, student characteristics, and whether any special learners were present. The coprolite activity had to be accompanied by educational objectives, and it had to identify which benchmarks (from the teacher's individual U.S. state) and U.S. National Science Education Standards the activity addressed. Activities also must attend to different learning styles within a single classroom, and include higher order thinking components. The coprolite assignment was valued at 40% for the homework exercises for that quarter.

Ichnofossil Pre-Assignment Survey

Before our teachers received their coprolite assignment, they were asked to access and complete an electronic pre-assignment survey (Appendix A). Survey questions probed our practicing teachers' incoming knowledge on ichnofossils (i.e., trace fossils, such as organisms' burrows and tracks) and their preservation, paleoenvironments, coprolites, and the history of coprolite/ichnofossil science. The survey also asked practicing teachers to predict their own students' interest in coprolites. After completing the pre-survey, teachers received the coprolite assignment as an individually e-mailed PDF file. This file also included a brief history of coprolites and William Buckland's role in initial coprolite identification and research. Once a teacher completed the assignment, the teacher submitted his/her project electronically.

End of the Semester Anonymous Survey

At the end of the semester, when grades were not affected, the practicing teachers were asked to participate in an anonymous electronic survey. The survey included open-ended essay questions that sought teachers' opinions of the coprolite activity and their perceptions of coprolite incorporation in K-12 Earth Science classrooms. Those questions that were analyzed and coded for the Paleo-Waste activity and coprolite inclusion are presented in Appendix B.

Paleo-Waste Incorporation by Semester

We incorporated the Paleo-Waste assignment in the online History of Life paleontology course over two semesters (N = 28). We introduced Paleo-Waste for the

first time as a second quarter laboratory assignment in 2007 (n = 16). Therefore, the practicing teachers who received this assignment had already been exposed, within our online classroom, to the fossil record, variation in fossils, and an introduction to trace fossils. Practicing teachers responded very positively to this coprolite assignment, and their anonymous survey responses encouraged us to incorporate the Paleo-Waste activities again in 2008 (n = 12). The 2008 practicing teachers were assigned Paleo-Waste in the first quarter of the course and completed the pre-survey before any course material or content—via video lectures, textbook chapters, and ancillary readings—was assigned.

Analysis and Results

Pre-Survey Results: Practicing Teachers' Ichnofossil Knowledge

We took the teachers' open-ended pre-survey question responses and developed a grading rubric for each response. Whereas some responses were easily scored as correct or incorrect (Appendix A, questions 7, 11), the other questions were graded based on the amount of correct information included as well as the presence of incorrect statements. We used a four-tiered system that included "excellent understanding" for thorough and complete responses; "good understanding" for correct responses that were not thorough or omitted a variable (such as the identification of only two ichnofossil types as opposed to three or more types); "partial/poor understanding" for responses with misconceptions but some correct information; and "poor understanding" for responses that were incorrect. A summary of responses, by semester, is presented in Table 1 and is organized by topic.

We predicted that our 2007 practicing teachers might perform better on the pre-survey assessment because of their introduction to fossils during the first quarter of the course. With certain questions, 2007 teachers did perform better than their 2008 counterparts. The 2007 practicing teachers (n = 16) exhibited better understanding of ichnofossil characteristics and the disadvantages of ichnofossil use (including difficulties in classification and responsible organism identification). Both 2007 and 2008 teachers exhibited fundamental knowledge of ichnofossil variety, the ichnofossil advantages, and ichnofossil use in environmental reconstruction. However, the 2008 teachers (n = 12) exhibited *better* understanding of original material preservation in ichnofossils, as well as the inherent difficulties in identifying a perpetrator.

Most teachers in both years did not originally self-identify coprolites as ichnofossils. (Each pre-survey question was administered one at a time, and teachers were not allowed to go back to questions or change their original responses.) Although most could not name early coprolite researchers, teachers could identify potential coprolite research opportunities. All but one practicing teacher listed her/his own students' probable interest in coprolites as high.

Project Performance and Teacher-Developed Classroom Activities

Practicing teachers performed well on their quarterly assignments with coprolites. Projects were scored through a summary rubric and expanded checklists that included both the research component (50% of the project score) and an application unit component (50%). For the classroom unit's required elements, the expanded checklist included identification of U.S. National Science Education Standards, identification of appropriate state benchmarks or standards, classroom description, appropriate level objectives, appropriate level of content (coprolite) presentation, active learning strategies, incorporation of higher-order thinking (by Bloom's taxonomy level), incorporation of the history of science, and appropriate assessment with grading strategies.

Project Performance on Paleo-Waste

A direct comparison of our teachers' scores on the Paleo-Waste assignment between the two semesters is not possible because of the differing points of incorporation for the Paleo-Waste activity. In 2007, the Paleo-Waste mean was 89.9% (n = 16). The entire second quarter laboratory mean of 2007 was 84.7%, indicating that teachers performed better on the Paleo-Waste component (40% of score) than the other laboratory component. In 2008, the Paleo-Waste mean was 86.0%, and the total first quarter laboratory mean was a similar 86.2%. However, the first quarter assignment is considered to be less difficult and time-intensive than the other quarterly assignments.

Teacher-Developed Coprolite Activities

In both semesters, practicing teachers developed a variety of activities for their own classrooms. In 2007 (n = 16), the majority of teachers utilized Web-based research activities with coprolites, modern scat investigations, or a combination of the two. Several teachers developed activities that reconstructed an organism's size, characteristics (feeding behaviors), and environment from its scat or coprolite. Several Web investigations accessed the large Saskatchewan theropod coprolite.

The 2008 practicing teachers (n = 12) submitted more diverse activities, including (1) calculation of animals' sizes through scat molds, and inference about eating

Table 1
Summary of Teacher Responses from 2007 to 2008 from the Pre-Assignment Ichnofossil Survey, Arranged According to Topic

Question	Excellent Understanding, %	Good Understanding, %	Poor/Partial Understanding, %
Ichnofossil characteristics			
2007	100	—	—
2008	50	25	25
Types of ichnofossils			
2007	93	—	7
2008	82	9	9
Advantages			
2007	87	7	7
2008	73	—	27
Disadvantages			
2007	100	—	—
2008	58	25	17
Original material preservation			
2007	33	60	7
2008	58	—	42
Environmental reconstruction			
2007	87	13	—
2008	83	8	8
Coprolite acknowledgment			
2007	47 (yes)	—	53 (no)
2008	25 (yes)	—	75 (no)
Coprolite perpetrator identification			
2007	79	14	7
2008	100	—	—
Coprolite data			
2007	100	—	—
2008	100	—	—
Coprolite research identification			
2007	93 (yes)	—	7 (no)
2008	100 (yes)	—	—
Early research			
2007	7 (yes)	—	93 (no)
2008	17 (yes)	—	83 (no)
Student interest			
2007	100 (high)	—	—
2008	91 (high)	—	9 (bimodal)

habits and environments; (2) group construction of "coprolites" with subsequent analysis; (3) Web-based research activities; (4) "Last Supper" and paleoenvironmental reconstruction from coprolites; and (5) student-created dichotomous keys to identify "poop-ertrators." The 2008 practicing teachers also interjected many appropriate-level books on coprolites and scat as well as *Jurassic Park* video clips. Both 2007 and 2008 practicing teachers successfully designed and developed coprolite projects for their own classrooms that (1) included the history of coprolite research; and (2) used coprolites as an introduction to other scientific topics of study, including ecology, paleoenvironments, geologic time, food chains and food webs, fossilization processes, and evolution.

Analysis of Teacher Perceptions on Coprolite Inclusion

Practicing teachers accessed the anonymous electronic survey at the end of the semester. Open-ended questions sought their opinions on the various activities of the semester, including the Paleo-Waste assignment (Appendix B). The essay responses were coded and analyzed via Neuendorf's (2002) content analysis guidelines. Several content variables emerged from an initial analysis, including various application activity topics (question 2), active learning, interdisciplinary science, self-directed learning, history of science, misconceptions in science, and classroom incorporation strategies. Identification of initial analysis variables was made at 100% inter-rater reliability. We further analyzed and coded variable categories. For example, "classroom incorporation strategies" were subdivided into additional categories, including "direct experience," "history of science research," "Internet-based research," "student-created models," "group learning," and "group presentations." Several stable themes emerged from content analysis: (1) Teachers thought coprolite study had scientific value in their classrooms; (2) teachers believed that student interest for this topic would be high; (3) activities to incorporate coprolite study in the classroom could spark student interest and present an interesting forum for science study; and (4) coprolites can be used to address several science topics.

The practicing teachers reported that prior to the online History of Life course, many of them had not been directly exposed to coprolites (46% in 2007, 40% in 2008). However, the practicing teachers did recognize the value in coprolites: Only one teacher (2007) did not anticipate interest in coprolites in his/her own Earth Science classroom. One teacher noted that "at the NSTA [National Science Teachers Association] convention, I purchased several coprolites for use next year in my classroom." There were many affirmative responses from practicing teachers about coprolites in our online History of Life class, with several teachers requesting that we "never change the coprolite assignment." The scientific value of coprolites in K-12 classrooms was also affirmed. One practicing teacher (2007) remarked, "Coprolites often precipitate more questions than body fossils, from an emotional perspective." Practicing teachers also identified an interest factor in their own students. A 2008 teacher stated, "Students LOVE this topic. It's not only interesting in a geologic sense, but it has that 'Ewwwww' factor that sometimes can be a HUGE draw to students." A 2007 teacher noted, "Keep the coprolite activity, it is one of those activities that some students will do that will hook them forever into science (especially geology)."

Discussion and Implications

Coprolites are one of the most interesting topics that students research in paleontology classes. Through this research investigation, practicing teachers also affirmed the educational potential of coprolites in K-12 Earth Science classrooms. With an introduction of the rich history of coprolite investigation and the use of coprolites as marquee fossils, teachers can stimulate classroom interest in these fossils and use them to springboard into other scientific topics, such as geological time, ecology, environmental science, food chains, and evolution.

Although some may consider "bathroom topics" as an improper venue for classroom discussion, our practicing teachers and their students find the forbidden nature and base humor of coprolites stimulating in the science classroom. The teachers developed a variety of creative and effective activities in which to introduce and study coprolites in their classrooms. These teacher-developed activities engaged students of various ages in measuring, hypothesizing, and inferring about modern and extinct organisms and environments. Initial coprolite investigations were used to initiate study of related topics in more detail, including environmental science, fossilization processes, and ecology.

Our investigation did not address Life Science courses, but many of the topics addressed by coprolites are included in biology courses as well. Coprolites may offer an interesting portal in Life Science classes to the study of environmental science, food chains, and evolution. Many U.S. National Science Standards can be addressed through coprolite introduction, including Unifying Concepts and Processes (evolution and equilibrium); Science as Inquiry (understanding the nature of science); Life Science (characteristics of organisms; life cycles of organisms; organisms and environments; populations and ecosystems;

diversity and adaptations of organisms; biological evolution; interdependence of organisms; matter, energy, and organization in living systems; behavior of organisms); Earth Science (Earth's history, energy in the earth system, origin and evolution of the earth system); Science in Personal and Social Perspectives (changes in environments, environmental quality); and History and Nature of Science (science as a human endeavor, nature of science, history of science, historical perspectives).

Teachers who want to include coprolites in their science classrooms can find a wealth of "coprolitic resources." Coprolites and modern scat are discussed in several children's books (Berkowitz, 2006; Hammerslough, 2006; Robson, 2004) and are the subject of popular science discussion (Williams, 2008; Witten, 2005), and current newsletters and news postings (Boswell, 2008; National Public Radio, 2008; Thermo Fisher Scientific, Inc., 2008).

William Buckland's colorful personality and his early scientific research on coprolites are an interesting addition to the Earth Science classroom. Geologists of the 19th century also recognized the inherent draw of coprolites on the observer. Rupke (1983) attributes the following verse to P. B. Duncan:[5]

> Approach, approach ingenuous youth
> And learn this fundamental truth
> The noble science of Geology
> Is bottomed firmly on Coprology
> For ever be Hyenas blessed
> Who left us the convincing test
> I claim a rich coronam auri
> For the thesauri of the Sauri

We propose that our modern Earth Science classrooms could still "bottom firmly on coprology" through an introduction of coprolites—leading to further study of some of the important constructs in the curriculum. Educational progress does not always translate into the development of new techniques or use of electronic technology. A reintroduction of William Buckland's enthusiasm for coprolite research may develop even the youngest of fossil aficionados in our Earth Science classrooms.

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Authors' Notes

[1] John Stevens Henslow was a graduate and appointed Fellow of St John's College, Cambridge. His letter to William Buckland is archived in the Oxford University Museum of Natural History (Letters Box 1/E 2).

[2] The correspondence of Gideon Algernon Mantell, English physician and geologist, to William Buckland is archived in the Oxford University Museum of Natural History, Buckland letters, Box 1/E 2).

[3] William Prout's letter is archived in Letters Box 1/14, while a letter with pencil drawings of coprolites, potentially attributed to Jaegar, is archived in Box 1/E 2. Buckland's miscellaneous manuscripts also contain notes on coprolites (No. 7, No. 10–11). All archived materials are held in the Oxford University Museum of Natural History.

[4] The original watercolor by Henry De la Beche is archived at the National Museum of Wales (De la Beche letters 368) and differs slightly from the lithographic image shown in Figure 5. De la Beche decided to add a shark to the original, and it is sketched at the back of the original watercolor. There are several copies of the *Duria antiquior* lithograph, but the one reproduced here was hand colored. It is archived in Murchison's letters within the Library of the British Geological Survey. Robert Farron, a curator of Adam Sedgwick's, painted the oil copy that now hangs in the Jurassic area of the Sedgwick Museum of Earth Sciences at Cambridge University.

[5] Verses on coprology are archived in the Buckland miscellaneous manuscripts (1–3) in the Oxford University Museum of Natural History. Two sheets, one of which is laminated, are preserved. Although Rupke (1983) identified Duncan as the author of the verse, in the Oxford archives, the author is not identified.

Appendix A

The Pre-Assignment Ichnofossil Survey

In the pre-assignment survey, teachers accessed the online survey at their convenience. Only one question was presented at a time, and teachers were not allowed to return to questions to change responses. There was no penalty for incorrect or partially correct answers, but all teachers had to access and complete the survey before the Paleo-Waste assignment directions were e-mailed to them. The questions, in the order presented to the teachers, are as follows:

1. What exactly is a trace fossil?
2. List as many different types of trace fossils as you can.
3. What is an advantage, if any, that a trace fossil has over a body fossil?
4. What is a disadvantage, if any, that a trace fossil has compared to a body fossil?
5. Do trace fossils ever preserve original material?
6. How do scientists reconstruct an environment or responsible organisms from a trace fossil? Is this an easy or difficult task?
7. Did you mention "coprolite" earlier in your listing of trace fossils? (It's okay if you didn't!) Do you know what a coprolite is?
8. In case you didn't know, a coprolite is the fossilized fecal remains of an organism! (It is fossilized "poop.") Can scientists easily tell which organism is responsible for the coprolite? Why or why not?
9. Can scientists gather any data from the coprolite ABOUT the organisms? If you think "yes," what type of information do you suspect that scientists can discern from coprolites?
10. Can you think of any experiment that you can do to verify that the information you can gather from a coprolite is, in fact, possible? (Try to come up with at least one suggestion.)
11. Who is the person who is credited for identifying coprolites as fossilized feces?
12. Do you think your class would be interested in coprolites? Can you think of any activity you might do with coprolites, and whether this would be beneficial to your students?

Appendix B

End-of-Semester Anonymous Survey Questions

The end-of-semester survey is designed to elicit feedback from enrolled teachers on the course's content, methods of delivery, and suggestions for improvement. Because the survey is designed for each course, several of the questions are not used between semesters as they apply to a specific semester only.

The following questions are a subset of the end-of-semester survey questions that practicing teachers enrolled in the 2007 and 2008 History of Life course received. These questions were coded and analyzed using Neuendorf's (2002) content analysis guidelines.

1. Do you find application exercises—such as the Paleo-Waste project—to be a good alternative and/or supplement to traditional laboratory exercises?
2. Of your application projects, which was your favorite? Why?
3. Before this class, have you had any direct experiences with coprolites?
4. What type of interest do you perceive your students would have in the topic of coprolites?
5. What data do you think should be collected in the field in order to make the fossils found there scientifically useful?
6. What is the one thing you liked MOST about this class? What should we never consider changing about this course?
7. If you could change ONE thing about this course, what would it be?
8. Please feel free to offer any additional comments about this course.

Effect of STEM Faculty Engagement in the Math and Science Partnership Program

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The article explores the effect of the engagement of university science, technology, engineering, and mathematics (STEM) faculty in the Math and Science Partnership program. The findings suggest that K-12 teachers benefited from the engagement in terms of improved approaches to teaching and learning, increased knowledge of subject matter content, and increased confidence. STEM faculty benefited from new ideas about teaching and learning, insights into research, more knowledge of the K-12 education system, and a broader understanding of education overall. Student achievement also improved, although direct attribution to faculty involvement is somewhat unclear. Furthermore, in the short run at least, it appears that few benefits extend beyond those faculty who are direct participants, and few systemic changes have been made in institutions of higher education systems.

The Math and Science Partnership (MSP) program at the National Science Foundation (NSF) is a major national research and development effort that supports innovative partnerships among institutions of higher education (IHEs), local K-12 school systems, and local K-12 school systems' supporting partners to improve K-12 student achievement in mathematics and science. Deep engagement of science, technology, engineering, and mathematics (STEM) disciplinary faculty is a hallmark of the MSP program. The program posits that the disciplinary faculty holds the content knowledge that K-12 teachers need and that if the faculty are substantially involved, teachers' disciplinary knowledge will be strengthened, resulting in improved student achievement.

Partnership has become a magic word in educational reforms. Many reforms are stressing partnerships among institutions of higher education, K-12 schools and districts, and community-based organizations and businesses (Abbott et al., 1992). The MSP program and the U.S. Department of Education's Teacher Quality Enhancement effort have the explicit goal of forming partnerships between K-12 districts and IHEs to create innovative solutions to persistent instructional problems and help transform K-12 and IHEs. In the past, the IHE players in the K-20 partnerships were primarily education faculty. However, given the dismal mathematics and science performance of American students in international comparisons, there is concern that the education faculty alone cannot make the change that the public is expecting. The central assumption underlying the MSP program is that what K-12 teachers really need is content knowledge. In order to address the problem, STEM faculty must be the change agents.

Educational partnerships between universities and public schools are not new. There are, however, three reasons for the current interest surrounding such partnerships. First, the politics of education reform have created the need for at least symbolic association among educational stakeholders. Second, increased accountability for student achievement, coupled with the need for better prepared teachers, has placed pressures on public schools and IHEs to collaborate. Finally, K-12 schools and IHEs face similar problems—public criticism, lack of sufficient funding, limited public support or respect, low salaries, and faculty shortages (Sirotnik & Goodlad, 1988). School–college partnerships offer promise for simultaneous educational renewal (Goodlad, 1994). Common interests have brought together a strong convergence on four goals: improvement of student learning, preparation of educators, professional development of educators, and research and inquiry into improving practices (Teitel, 1999).

However, there are many obstacles to successful partnerships. Kochan (1999) cautioned that partnerships face communication problems, encounter conflicting values, and demand an enormous consumption of time and energy, resulting in inconsistent commitment and lack of shared program development and ownership. More troubling is that little is known about the impact of STEM faculty involvement in the partnerships. In their latest review of partnership literature, Clifford and Millar (2008) concluded that the empirical foundation supporting claims about the value of K-20 partnerships was judged relatively

weak—often involving single-case studies, employing a convenience sample to assess partnership success, and identifying features associated with success but providing little data to support the claims.

Existing research suggests a positive impact on K-12 teachers from working with STEM faculty. An evaluation report of NSF's Collaboratives for Excellence in Teaching Program (CETP), which was designed to improve the preparation of future science and mathematics K-12 teachers through the use of STEM faculty, found that although CETP and non-CETP teachers generally reported similar frequencies of using instructional strategies, students of CETP teachers reported higher usage of real world and more challenging problems by their teachers than students in the comparison group. CETP teachers also were rated by outside observers more highly on 9 of 12 key indicators than non-CETP teachers (Lawrenz, Michlin, Appeldoorn, & Hwang, 2003). Evaluation of a five-year school–university partnership revealed impacts on teachers' instructional practices in terms of increasing use of performance assessments, experimenting with portfolios, engaging in cooperative learning activities, integrating mathematics into other subject areas, and teaching based on student understanding and interaction (Waddle & Conway, 2005).

The MSP Knowledge Management and Dissemination (KMD) project recently conducted a systematic review of the empirical literature related to deepening teachers' mathematics/science content knowledge (MSP KMD, 2009). Nine of the studies identified in the review examined professional development programs that were explicit about the involvement of STEM disciplinary faculty in that effort. Although no studies investigated the unique contribution of involving STEM disciplinary faculty in the deepening of teachers' content knowledge, consistent positive results across the programs support claims regarding their effectiveness in that regard.

Few studies have addressed the issue of student impact. Waddle and Conway (2005) and Mariage and Garmon (2003) found that student achievement, measured by state assessments, has improved either over time or in relation to the comparison schools.

Engagement in partnerships also benefited STEM faculty (Fedock, Zambo, & Cobern, 1996). Evaluating the mathematics and education reform forum, a voluntary association targeting the academic mathematics community in four-year colleges and universities, Haug and Marion (1996) found several benefits to participating faculty based on a survey of 731 participants, site visits, observations, and interviews. More than half of the faculty reported increasing awareness of issues in mathematics education as a result of the partnership. Another benefit was the creation of a supportive atmosphere for educational reform activities. Over 70% of respondents agreed that they felt more comfortable contacting colleagues in the partnership about professional matters. More importantly, almost half of the faculty members have changed their own teaching as a result of their involvement with the partnership including the incorporation of cooperative learning and technology, as well as the inclusion of more hands-on activities, more class participation, and new types of assessments.

Despite the considerable literature on partnerships involving STEM faculty, research on the impacts of STEM faculty involvement is limited. Many studies suggest a variety of benefits from engaging STEM faculty, but the suggestions have been based more on theory or anecdotal reports than on empirical evidence. In this article, we present findings to address two research questions: (1) What changes have occurred in the number of STEM faculty involved, the extent and variety of their involvement, and the nature of collaboration between STEM faculty and other participants?; and (2) what are the effects of STEM faculty engagement on teachers, students, and STEM faculty themselves?

Methodology

The study consisted of two components: case studies of eight MSP projects and an analysis of data collected from the MSP Management Information System (MIS) on all 48 of the first three cohorts' MSP intervention projects (i.e., 12 Comprehensive, 24 Targeted, and 12 Institute)[1] whose solicitations were issued between 2002 and 2004.

The eight case study projects were selected from the pool of 48 projects primarily because they were expected to include high levels of STEM faculty participation based on their proposals. Retrospectively, data from the MIS suggest that STEM faculty from those eight projects were representative of the MSP projects overall in aspects such as demographics, tenure status, and faculty rank. They differed mainly in their levels of substantive STEM faculty involvement.

Table 1 provides characteristics of the case study projects. Two projects focus on mathematics, three on science, and three on both mathematics and science. Among the lead institutions, four are classified under the Carnegie classification system as research university (very high research activity), one as research university (high research activity), one as doctoral/research university, and two as master's college or university (larger program). Six

Table 1
Characteristics of the Case Study Sample (Eight Projects)

Aspect	P1	P2	P3	P4	P5	P6	P7	P8
Content focus	M	S	M/S	M/S	M/S	S	M	S
Institution type of lead partner								
Carnegie classification								
Research university (very high research activity)			X		X		X	X
Research university (high research activity)	X							
Doctoral/research university				X				
Master's college or university		X				X		
Ownership								
Public	X	X	X		X	X	X	
Private				X				X
Location								
East				X		X		X
South	X							
Midwest					X			
West		X	X				X	
Total number of IHE partners	2	5	1	2	5	4	10	1
Total number of K-12 district partners	15	29	3	10	8	2	10	17

Note. Data are from MSP MIS; case studies.
P = project; M = mathematics; S = science.

of the IHEs are public and two are private. Geographically, they are located in the east, midwest, south, and west. The number of IHEs within a partnership varies from 1 to 10. The number of K-12 districts ranges from 2 to 29, with an average of 10.

We conducted annual site visits to the eight projects to describe faculty engagement over four years and the changes that occurred during that time. Site visits often included interviews (project leadership, STEM faculty members, department chairs, in-service teacher leaders and teachers, principals, and district content/curriculum specialists) and classroom observations of STEM faculty and K-12 teachers with whom STEM faculty have worked. The interview questions were linked to respective research questions, reflecting both the roles of the respondents and the maturity of the project. The semistructured, open-ended question format allowed for additional questions or probes to be used, as determined necessary by the interviewer. We conducted observations in classrooms and at a variety of meetings. The annual site visits were conducted by teams of two: a researcher and a STEM disciplinary faculty member from a non-MSP university. The inclusion of a STEM faculty member as a co-site visitor both established a rapport between respondents and researchers and helped to interpret the data in a more culturally sensitive way.

The literature guided some of the coding and analysis of interview notes and documents (Patton, 1990), but codes primarily emerged from the data. The data analysis followed the process of (1) developing preliminary coding categories from the research questions and confirming or modifying those categories as information was gathered; (2) reducing the data to manageable chunks of information for identifying themes or patterns of response; and (3) drawing conclusions by comparing within-case and across-case themes and patterns (Miles & Huberman, 1994). Essentially, we used two forms of triangulation. Within each project, evidence was triangulated from interviews

and observations. Across projects, evidence was compared and contrasted in the context of each project.

We also analyzed survey data on all 48 projects from the MIS. One component of the MSP program is the administration of annual surveys to the partnership projects we developed. The data provide an overall picture from all intervention projects. The MIS consists of multiple modules, three of which are relevant to our study: the IHE participant survey, the IHE institution survey, and the K-12 district survey. The IHE participant survey and IHE institution survey request information on STEM faculty involvement from MSP projects with regard to faculty profiles, extent of engagement, types of engagement, etc. The district survey collects aggregate teacher and student data from participation schools.

Around 1,100 people have responded to the IHE participant survey every year since 2004–2005, about 700 of whom can be categorized as STEM faculty. We defined STEM faculty as those who either teach in a STEM field or whose research is in a STEM area. Our analysis examined the three-year trend for STEM faculty from 2004–2005 to 2006–2007 using descriptive and inferential statistics. We also contrasted the responses in 2006–2007 between STEM faculty and education faculty. The significance tests were used to test whether the changes in the characteristics of STEM faculty, the type and level of their engagement over three years, and the contrast between STEM faculty and education faculty were statistically significant. Analysis of variance was used for interval type of variables, and chi-square test was used for categorical variables.

Finally, we explored the relationship between project-level STEM faculty participation and school-level student achievement reported by the K-12 surveys of 2003–2004 through 2006–2007. Using three-level hierarchical linear models (HLM), we modeled the relationship between student achievement (school-level percent proficient aggregated from grade-level data) and extent of STEM faculty involvement at the project level, controlling for the previous achievement level as well as project characteristics such as project type and cohort. We used different specifications to measure the extent of faculty involvement, including (1) total number of STEM faculty participating in the project to measure the overall scale of participation; (2) relative emphasis of STEM faculty involvement (percent of STEM faculty of total IHE participants or among total IHE faculty); (3) intensity of participation (average number of hours spent on the MSP); and (4) breadth of involvement overall or by specific types of participation in preservice, in-service, and project management, measured by factor scores based on survey responses.

Results

The results provide insight into the STEM faculty engaged in MSP, how they were involved, and the impacts of their involvement.

STEM Faculty Profile

About 65% of the IHE participants in 48 MSP projects were STEM faculty and 27% were education faculty. Although the number of IHE participants decreased slightly from 1,163 to 1,040 over three years, the composition remained stable.[2] We do not know whether the number of STEM faculty can be considered to represent a large or small scale relative to department size because there is no benchmark for comparison. The case studies suggested that in some highly involved departments, STEM faculty participation was about 20% of the total disciplinary faculty. However, in many cases—especially for nonlead institutions—STEM faculty participation was often more an individual act rather than an institutional effort.

Table 2 shows that about 60% of the STEM participants were male and 85% were White among the 48 projects. STEM faculty were far more likely to be male than education faculty, which probably reflected the departmental differences. Compared to the national data in four-year universities and colleges (2003 Survey of Doctorate Recipients [SDR]),[3] MSP STEM participants shared a similar racial composition but had 10% more females. The data also show that although many disciplinary faculty members involved in MSP have had previous experience working with the K-12 sector, 32% of the STEM faculty reported that MSP was their first experience in working with K-12 students and teachers.

Compared to education faculty, STEM faculty were more likely to be tenured and to have more senior positions (Table 3). Overall, 61% of the STEM faculty had tenure, and 55% were either full professors (31%) or associate professors (24%). In contrast, only 38% of the education faculty had tenure and 32% were full or associate professors. Compared to the 2003 SDR data, the MSP STEM participants had similar profiles in faculty rank but were 10% more likely to be tenured. Half of the STEM faculty were from doctoral-granting institutions. In contrast, slightly more than 10% were STEM faculty from associate's colleges or specialized institutions. This was largely due to the fact that community colleges could not be the lead institution on an MSP grant.

Table 2
Demographic Characteristics of IHE Faculty in MSP (All 48 MSP Projects)

Characteristic	STEM 2004–2005 (n = 742) (%)	STEM 2005–2006 (n = 717) (%)	STEM 2006–2007 (n = 680) (%)	Education 2006–2007 (n = 282) (%)
Gender				
Male	61.9	60.9	60.3	34.8*
Female	36.4	35.6	35.3	59.6*
Race				
White	86.3	86.3	83.7	78.4
Black	3.8	3.1	3.5	6.7
Asian	4.0	4.5	5.4	5.0
American Indian	.5	.1	.4	1.1
Native Hawaiian	.5	.4	.4	.0
More than one race	1.9	1.4	1.0	1.4
Ethnicity				
Hispanic or Latino	11.5	11.4	11.3	11.3
Not Hispanic or Latino	85.7	84.2	83.5	81.2

Note. Percents may not add to 100 because of nonascertained responses. Data are from MSP MIS IHE participant survey.
* Significant difference between STEM and education faculty in 2006–2007.

Engaging in K-20 reforms is not for every STEM faculty member. Some case study projects mentioned the importance of selective recruitment. "There are STEM faculty who I love and respect, but wouldn't let them near the project," said one principal investigator (PI). Although it is difficult to generalize, one common element was that many of the STEM faculty in the case studies initially became involved with K-12 schools because they had children in them or their spouses were teachers.

Many respondents from the eight case studies noted that it takes a "certain type of personality" for one to be effective in K-20 partnerships. An ideal STEM faculty participant often has the following traits: (1) possesses a high-quality disciplinary background and credibility; (2) is a good STEM higher education instructor and interested in how to teach more effectively; (3) has a dedication to changing the lives of students; (4) is open-minded to trying new approaches; (5) is able to deal with people who are coming from different content-level foundations; (6) is willing to work in teams, and on a lighter note as per one PI, (7) is "in touch with their inner adolescent."

Extent of STEM Faculty Engagement

The level of involvement was constant over three years (Table 4). Across 48 projects, about 75% of the STEM faculty spent over 40 hours in MSP activities, close to 55% reported over 80 hours of involvement, and about 35% reported over 160 hours of engagement. Compared to education faculty, the level of involvement from STEM faculty was slightly lower. Specifically, STEM faculty were significantly more likely to spend less than 20 hours and less likely to spend more than 200 hours.

For all 48 projects, the MIS investigates how STEM faculty are engaged in the MSP, as well as the extent of STEM faculty involvement in a variety of activities, i.e., teacher professional development, teacher preparation, teacher recruitment, curriculum alignment and revision, mentoring, and research. During 2006–2007, 67% of the STEM faculty were involved in in-service activities, whereas about 40% were engaged in preservice activities and project management, respectively. As expected, STEM faculty were less likely to engage in preservice and project management activities than education faculty.

Table 3
Tenure Status of IHE Faculty in MSP (All 48 MSP Projects)

Faculty type and tenure status	STEM 2004–2005 (n = 742) (%)	STEM 2005–2006 (n = 717) (%)	STEM 2006–2007 (n = 680) (%)	Education 2006–2007 (n = 282) (%)
Tenure status				
Tenured	59.6	61.8	63.2	37.6*
On tenure track	16.8	15.3	15.0	16.7
Not on tenure track	12.1	12.6	12.9	19.5
Not applicable to my position/at my institution	11.5	10.3	8.8	26.2
Faculty rank				
Professor	31.1	31.7	31.0	15.6*
Associate professor	23.0	22.5	25.1	16.7*
Assistant professor	18.3	17.4	16.9	20.2
Instructor	5.9	6.4	7.1	3.5
Lecture	4.4	3.9	5.0	2.8
Adjunct faculty	2.0	1.7	2.1	2.8
Others (e.g., administrators, NA)	15.0	16.6	12.7	38.2

Note. Percents may not add to 100 because of rounding. Data are from MSP MIS IHE participant survey.
* Significant difference between STEM and education faculty in 2006–2007.

Table 4
Hours of IHE Faculty Involvement in MSP (All 48 MSP Projects)

Hours of involvement	STEM 2004–2005 (n = 742) (%)	STEM 2005–2006 (n = 717) (%)	STEM 2006–2007 (n = 680) (%)	Education 2006–2007 (n = 282) (%)
Less than 20 hours	8.6	12.6	12.1	5.7*
20 to 40 hours	12.1	12.8	14.6	9.6
41 to 80 hours	17.5	15.8	17.4	13.8
81 to 160 hours	20.8	21.5	20.3	16.3
161 to 200 hours	11.3	8.9	10.6	9.9
More than 200 hours	29.6	28.5	25.1	44.7*

Note. Percents may not add to 100 because of rounding. Data are from MSP MIS IHE participant survey.
* Significant difference between STEM and education faculty in 2006–2007.

For in-service activities across all projects, the most common and consistent activities for STEM faculty were conducting workshops for K-12 teachers to increase general content and/or pedagogical knowledge and remaining on-call for classroom teachers. Over 20% of STEM faculty were involved in conducting targeted workshops, participating in activities to motivate students to take challenging courses, aligning curricula to standards, and helping teachers utilize technology. The pattern of STEM faculty engagement was similar to that of education faculty.

All eight case study projects involved STEM faculty in in-service professional development. We found a variety of models, and none of the eight projects were identical in their approaches and strategies. Some general observations follow:

1. Providing professional development for in-service teachers was the main focus for STEM faculty involvement in seven of the eight case study projects. For the one remaining project, the main focus of STEM faculty involvement was direct outreach activities with K-12 students.

2. With the exception of one project, STEM faculty worked in teams. They collaborated with teacher leaders in seven projects and with education faculty in four projects.

3. Of seven projects involving team efforts, STEM faculty played a leading role in two, served as equal peers in four, and were in a supportive role in two projects through acting as content resources for hands-on activities or laboratory sessions. However, as the project matured, for at least three MSPs, the role for STEM faculty seemed to diminish from providing direct instruction to teachers to focusing on research and observation in the final years.

4. Three projects viewed STEM faculty contributions primarily in terms of providing content, whereas in three other projects, STEM faculty were involved in both content and pedagogy. For the remaining two projects, STEM faculty were asked to determine their roles to best complement the teams—an approach not recommended in the literature on STEM faculty engagement.

Across all 48 projects, more than 20% of the STEM faculty with over 40 hours of annual MSP participation reported involvement in teaching a preservice content course and in mentoring preservice students. The patterns of involvement of STEM and education faculty were different, with a higher level of engagement from education faculty. For example, education faculty more often engaged in activities such as mentoring preservice students, developing/revising courses to align with standards, providing students with teaching experience before formal student teaching, involving K-12 master teachers in the preservice program, and participating in efforts to link the preservice process to national teacher certification activities. In general, STEM faculty reported a lower level of involvement in project management compared to that of education faculty.

Impacts of STEM Engagement

In this article, we focus on findings about impacts of STEM faculty involvement on individuals: K-12 teachers, students, and STEM faculty. Because STEM faculty were involved as part of the partnership, we look at the effects of value added by STEM faculty participation.

K-12 Teachers. Findings from eight case studies suggest that STEM faculty involvement had some positive effect on teachers in the areas of content, pedagogy, and confidence—at least in the short term. We will explore each in turn. One caveat is that STEM faculty involvement was rarely seen to be the sole or even the main contributor to the changes observed. There were disagreements on the relative strength of impacts among different respondents.

Content. For many, the dichotomy between content and pedagogy is artificial and moot. Teachers often told us, "You can't have one without the other" and "I've learned a lot of content, but there is so much pedagogy wrapped up in content." Many teachers viewed STEM faculty as providers of content. They appreciated the depth and breadth of knowledge that STEM faculty offered and saw that knowledge as more extensive than what they normally received from other professional development providers. "The other professional development never caused me to think much because they were too easy and often dealt with what we cover in class. This is more about problem solving and application to the real world." In general, participants noted the content focus of MSP. One teacher pointed out, "This is the first professional development I have had about content." Teachers acknowledged that STEM faculty brought different levels of understanding and maturity to the content. Faculty helped teachers break things down.

Generally, teachers appreciated that STEM faculty had "high standards for content and the content knowledge is geared towards educators and at a right level." As one teacher said, "The program kicked my butt, but it was well worth it." It appears that teachers' gain in content knowledge depends on several factors. Not surprisingly, teachers were more likely to report content knowledge gains from projects that emphasized content. The second factor regards the utility of the content knowledge. Many teachers valued what can be applied directly to the classroom, whereas others wanted the broad pictures and issues.

We found that teachers were often less concerned about content itself; what they needed was how to get the concepts across. Some teachers felt that STEM contributions were too content driven, and what they needed was "content in context." One teacher said, "The level of content detail that STEM faculty insisted on was too much for the students and prevented teachers from finishing the curriculum." Gains in content also varied from teacher to teacher and by grade level. Teachers with stronger content backgrounds stressed new ways of presenting materials and guiding discussions, whereas those without content backgrounds, most often the elementary school teachers, emphasized content knowledge gain as well as the new teaching strategies.

At the beginning, most STEM faculty members were insistent that teachers would learn content more than pedagogy. One said that teachers "have to have this" and need to take courses beyond what they teach, and STEM faculty were in a unique position to help teachers to see beyond the range of K-12 concepts. Some STEM faculty members were skeptical of the pedagogical strategies advocated by projects. Ironically, although one project was built on a collaborative learning model, some STEM faculty came to the project wanting to "model excellent teaching." One faculty member reflected in retrospect:

> We were way too naïve. We thought we could take content experts and mix them with high school teachers. Teachers would suck up the content that STEM faculty would provide with innovative pedagogy. Well, it works only when you have a perfect faculty—which is rare. What we found is that a typical STEM faculty is not comfortable with high school teaching.

As STEM faculty became more involved in the projects, they admitted that adjustments needed to be made in courses and expectations because of the range of skills and knowledge among teachers. Additionally, there was an increasing realization among STEM faculty that pedagogical skill was at least as important as content knowledge for K-12 teachers.

Pedagogy. Although MSP puts a premium on STEM faculty's contribution to content, many teachers emphasized gains in pedagogy for mathematics and science from the project. This might be a function of how the content was taught. Although not part of an MSP requirement, the majority of projects employed inquiry approaches encouraged by STEM education professional associations such as the National Council of Teachers in Mathematics, and National Science Teachers Association. In addition, some K-12 teachers and principals maintained that "content is not the problem, but how to get the content across to students." Where professional development was not grade specific, teachers might be more likely to see benefits in pedagogy rather than content, as the latter was generally less transferable to classrooms. Because STEM faculty were not primarily charged with reforming teacher pedagogy, it was unclear how much of the pedagogical benefit could be attributed to them.

We observed many elementary and middle school classes taught by MSP teacher participants. We frequently saw that teachers divided the class time into lectures, group activities, different levels of questioning, and peer grading. Many teachers appeared to be comfortable in delivering the content and having students take more responsibility. Teachers asked "why" questions, probed student reasoning processes, and used new techniques and manipulatives. Examples of effective incorporation of exercises, graphing, and independent problem solving were abundant. Despite overwhelming testimony of self-reported gains in instructional practices, our observations indicated that the transfer of project-gained knowledge into K-12 classroom practices was not a certainty. About one third of the classrooms we observed exemplified the transfer of project-gained knowledge and practice, half were in transition, and one-fifth was struggling with the change.

Confidence. Teacher confidence is another area in which gains were consistently reported. Almost all teachers reported that they had more self-assurance and confidence in how to go about learning and teaching because of MSP. Many teachers regarded MSP involvement as life changing. As one said, "Nothing is the same with my teaching." Greater content knowledge and pedagogical skill often led to higher confidence. In addition, teachers were thrilled about STEM faculty involvement because it showed what they were doing was valued. "It is motivational and you get a sense of being respected." One teacher noted: "I felt so much more comfortable about opening up the floor for students to ask questions. I didn't feel like my lessons had to be as closed and scripted because I felt I could probably answer them. And if I couldn't, I had somebody to call who could help me answer them too."

A related sentiment is that "the association with STEM professors makes us (teachers) look better and feel better." More importantly, teachers added that STEM faculty could validate their solutions when teachers need to find arbitration. Teachers derived a sense of self-respect and the feeling of being professional. Another source of confidence came from connections with like-minded teachers from other schools, which was especially important for

teachers from small schools. In some cases, teachers also became more aware of cross-disciplinary connections, more open to constructive criticism from peers, and more confident and motivated.

As a result, teacher participants were more willing to take lead roles in schools. Many put on sessions for other teachers in their schools or in the districts, often based on topics and concepts covered at the MSP. In addition, one master teacher indicated that as a result of his MSP involvement for the first time, a procedure was put in place to allow teachers to explore a new career track as adjunct faculty at the participating universities while maintaining their status as school district employees.

K-12 Students. Although most STEM faculty did not work with K-12 students directly, the expectation was that the effect would filter through teachers. Both K-12 and IHE respondents from the eight case studies expressed a spectrum of views about the impact of STEM faculty involvement on student achievement. Some were more affirmative: "We won't get involved if we don't know if there are impacts." Others were less positive, citing that STEM faculty were "two orders removed from students" or that because there were many confounding variables in student achievement, including that with existing assessment tools, some important skills and knowledge may not get tested. Regardless of the perceptions, all respondents were anxious to look at student performance as validation of project success.

Achievement. There was some evidence that student achievement was going up, with a higher percentage of students meeting the standards. However, few K-12 respondents from the case studies were comfortable attributing the progress to STEM faculty involvement, and STEM faculty were even more cautious in doing so. Some were frustrated about a lack of evidence on student achievement. "I would like to prove something—that it is really having an effect," noted one project leader. On the other hand, a project evaluator commented, "I don't think we are ever going to be in the position to do that." The inability to make attribution has to do with both project design and evaluation methodologies. STEM faculties are primarily working with teachers and not directly with students.

Drawing on three years of data from 2004–2005 through 2006–2007 gathered by the MIS annual surveys from all 48 projects, we explored the relationship between STEM faculty participation and student achievement. For student achievement analysis, we distinguished two outcomes: mathematics achievement and science achievement measured by percent proficient at the school level.[4] Only schools that used the same assessment and proficiency criteria were included. The sample for the mathematics model included 22 projects and 611 schools; the science model analyzed data from 11 projects and 299 schools.

Figure 1 presents the trends for student math achievement for the three-year model. The *x*-axis represents school-level percent students at or above proficiency. The *y*-axis shows the number of MSP schools. Each curve demonstrates the distribution of student achievement in a given year. The average percent proficient for each year can be located on the *x*-axis, corresponding to the top of the bell curve. The model shows that the average percent proficient improved from 57% in 2004–2005 to 59% in 2006–2007. Figure 2 illustrates the trends for student science achievement for the three-year model. It shows that the average percent proficient improved from 45% in 2004–2005 to 48% in 2006–2007.

Tables 5 and 6 present the results from the HLM analysis examining whether student achievement is significantly related to school's participation in the MSP project as well as STEM faculty involvement. For both tables, the rows reflect the variables associated with the three levels of modeling: observation level (time), school level, and project level. For each subject, we specified five models to reflect the intensity of STEM faculty engagement as measured by total number of STEM faculty (Model 1), percent STEM faculty relative to all participants (Model 2), percent STEM faculty relative to IHE participants (Model 3), average hours STEM faculty involved (Model 4), and

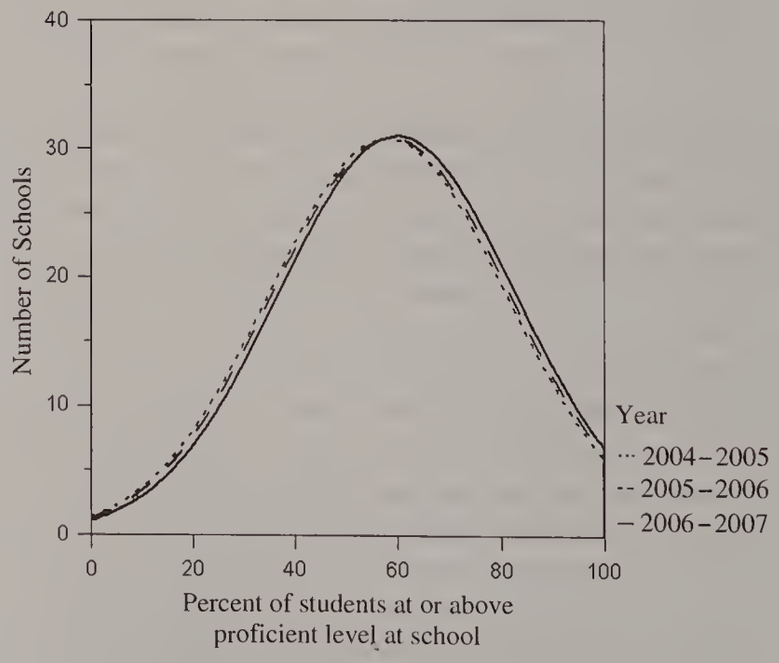

Figure 1. Trend for percent of students at or above proficient level for mathematics (all MSP projects). Note. Data are from MSP MIS.

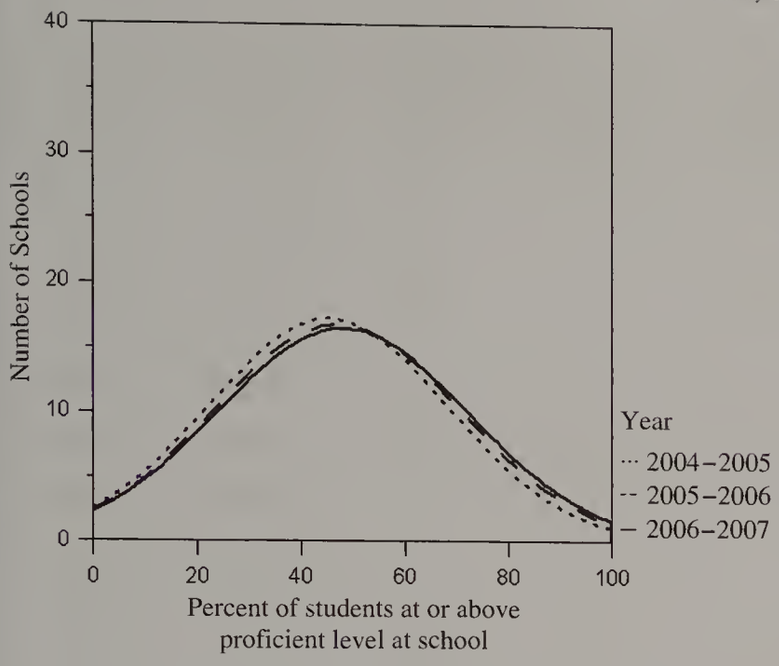

Figure 2. Trend for percent of students at or above proficient level for science (all MSP projects). Note. Data are from MSP MIS.

total participation in all types of MSP—an index score derived from factor analysis based on faculty responses to the survey (Model 5).The results suggest that annual growth in mathematics and science achievement at the school level (i.e., time variable) was statistically significant. However, variations among MSP projects regarding the extent of STEM faculty involvement, as measured by multiple proxy variables, were mostly unrelated to student mathematics and science achievement in the schools participating in MSP projects. Nevertheless, total number of STEM faculty and percent of STEM faculty relative to all IHE participants appeared to be significantly associated with achievement level in a positive way. However, the association was negative for average hours of STEM faculty involvement. The results provide some support for the hypothesis that MSP participation leads to improvement in student math and science achievement, and that an emphasis on STEM faculty involvement may have been associated with the increase.

Motivation. Case studies show that other student impacts are more subtle. For example, most teachers from one project recognized improved math discourse in their classes and attributed the improvement to their MSP experience. Some felt strongly that there were signs that students were making progress: "Students are coming to the next grade with greater sense of what it means to 'talk math' and can communicate their thinking more." In another example, the district specialist noted that the main impact was the increase in students' ability to understand and think more deeply, which in the long run would translate into achievement. Teachers also observed that students were more confident about thinking on their own and volunteering in classes. One student told the teacher, "It is not like being in a math class." The principal also noted more student engagement and interaction because math is no longer just "lecture with workbook." Students were talking and writing about math now, which "never happened before."

Increased K-12 student motivation and more favorable attitudes toward mathematics and science were attributed to project participation by many teachers interviewed throughout the four years of site visits for another project. For example, a "day at college" activity from one MSP project not only incorporated a visit to a university campus, it also was designed to meet state content standards. As one teacher said, "The students are having fun and learning—and we are actually doing what the state requires!" Another noted, "The hands-on experience in a college setting is very inspirational to the students."

STEM Faculty. The MSP views STEM faculty as a change agent whose involvement will benefit teachers and students. However, one of our major findings from the eight case studies was that STEM faculty members derived considerable benefit from their engagement. The fact that many of the same faculty had worked with the MSP projects from the beginning reflects ongoing interest and motivation, and most likely, a mutually beneficial relationship. Changes in STEM faculty are reflected in three separate areas: their own teaching, understanding of K-12 perspectives, and research.

Teaching. We often heard STEM faculty use words such as "most rewarding," "positive," "invigorating," and an "eye opener" to describe their project experience. Faculty members from six of the case study projects citied benefits for their own instruction in that the experience made them think about content, exposed them to pedagogy, and to varying degrees, changed their existing approach to pedagogy. One STEM faculty concluded, "It (the MSP) pushes me in new directions content-wise and pedagogically. It's been fun—challenges me."

The major impact was that MSP made them better teachers. A personal "aha" was the discovery of active teaching strategies, which has reshaped faculty members' ideas about student learning. Many STEM faculties noted that they received no training in pedagogical methods during graduate school and had to learn on the job. The types of changes STEM faculty had made in their own university courses included using more questioning, working with groups, making connections with student

Table 5
HLM Results for School-Level Percent Proficient in Mathematics (All MSP Projects)

Variable	Model 1	Model 2	Model 3	Model 4	Model 5
Intercept	50.38***	52.60***	50.84***	44.84***	50.17***
Observation-level predictors					
Time	1.05*	1.05*	1.05*	1.05*	1.05*
School-level predictors					
Percent minority	−.29***	−.30***	−.30***	−.29***	−.29***
Middle school	−19.32***	−19.22***	−19.18***	−19.34***	−19.24***
High school	−17.36***	−17.24***	−17.18***	−17.40***	−17.29***
Project-level predictors					
Cohort 1	−.61	2.24	5.88	6.33	3.07
Cohort 2	3.25	7.00	7.69	11.28	7.42
Project type (1 = targeted, 0 = comprehensive)	8.79	.51	.49	7.53	3.81
Total STEM faculty	.07*				
Percent STEM faculty relative to all participants		.21			
Percent STEM faculty relative to IHE participants			−.26		
Average hours STEM faculty involved				−8.61*	
Overall participation of all types of MSP activity					−3.39

* Significant at .10 level; ** significant at .05 level; *** significant at .01 level.

prior knowledge, introducing concepts in context, and teaching for diversity. These changes were more of a constructive, inquiry-based, and hands-on approach than the lecturing methods they had used in the past. For others, such strategies were an extension of what they were already doing purposefully or intuitively. However, not all of the STEM faculty were transformed overnight. Some acknowledged, "I still do a lot of lecturing but I am working on it." Still, others continued to be skeptical about some of the pedagogies advocated by the projects.

K-12 Knowledge. A second major impact on faculty was deeper knowledge of K-12 schools, and the challenges faced by the teachers. STEM faculty in all eight case study projects agreed that the experience helped them think about education and its goals on a broader basis, not just at the university level. As a result of MSP, faculty had more appreciation for what teachers have to do at K-12 schools, and in some cases, they even learned from K-12 practices.

Research. Some STEM faculty acknowledged difficulties in transferring their project knowledge into their own professional lives. One project tried to help channel faculty experience into scholarly research by bringing together STEM faculty, education faculty, and PhD candidates to engage in STEM pedagogical research. In a few cases, STEM faculty published articles on mathematics and science education research or wrote proposals to NSF and other agencies. Further, participation in MSP made STEM faculty aware of the types of education research funded by NSF. Another major change for the faculty was to learn about and to develop appreciation of social science research. One faculty member commented, "I was under the mistaken impression that pedagogical research was at a lower level and was paper thin. I now have an appreciation for the importance and depth of pedagogical research." STEM faculty also noted improved connections with peers from other IHEs and disciplines. Other faculty cited that the experience of working on course design, interaction with other participants, and new research opportunities were beneficial. One junior faculty told us that working with large groups of teachers had expanded his personal horizon: "In my own research work, I work with no more than three people."

Table 6

HLM Results for School-Level Percent Proficient in Science (All MSP Projects)

Variable	Model 1	Model 2	Model 3	Model 4	Model 5
Intercept	37.32**	45.67***	48.50**	53.39***	45.27***
Observation-level predictors					
Time	1.41**	1.41**	1.41**	1.41**	1.41**
School-level predictors					
Percent minority	–.51***	–.51***	–.52***	–5.79***	–.52***
Middle school	2.53***	3.02***	2.50***	2.65***	2.64***
High school	–5.85***	–5.74***	–5.77***	–.50***	–5.83***
Project-level predictors					
Cohort 1	24.64**	24.10**	24.35*	5.12	21.8*
Cohort 2	18.43	4.79	9.30	9.73	18.76
Project type (1 = targeted, 0 = comprehensive)	–.74	–5.37	–12.33	–7.32	–11.09
Total STEM faculty	.07				
Percent STEM faculty relative to all participants		.58*			
Percent STEM faculty relative to IHE participants			–.72		
Average hours STEM faculty involved				–20.28*	
Overall participation of all types of MSP activity					–6.17

* Significant at .10 level; ** significant at .05 level; *** significant at .01 level.

The impact on nonparticipating STEM faculty appeared to be minimal. We were told that nonparticipants usually did not care one way or the other. One STEM faculty said his colleagues "are probably tickled to death with what we are doing." A project director estimated that three-quarters of the faculty did not even know about their MSP institute, even though 10 of their fellow STEM faculty were involved. "We are generally 'under the radar' within the School of Arts and Sciences." Another faculty member pointed out that the lack of interest has to do with university culture—faculty usually do not care about what others are doing because "everybody is busy with their own things."

Although the main focus of this article is the impact on individuals, we also found many K-12 changes that occurred at the teacher, school, and district levels can have a lasting impact. The most significant one was the change in the mindset of teachers as they continued to apply the content knowledge and used the pedagogical approaches they had learned. There were examples of emerging professional learning communities, as well as institutionalization of instructional practices, changes in the hiring processes, and resource allocation.

At the higher education level, the MSP experience impacted STEM faculty teaching practice even though the effect was primarily on participants. We also saw many examples of changes in courses and curricula that were likely to have a lasting impact. Changing tenure and promotion policies is a slow process. We found small steps made toward either elevating the status of outreach/service directly or redefining MSP activities in terms of research or teaching. However, faculty perceptions about tenure and the reward system remained the same.

Limitations

We acknowledge two major limitations to the study. First, in making statements about impacts, we must consider several caveats. For purists, causal claims can only be made based on results from experimental design involving random assignment, whereas others often use causality casually. For this project, we acknowledge the difficulties and are explicit about the limitations concerning impact

statements about STEM faculty involvement. Foremost, the study lacks reasonable counterfactuals. In addition, as discussed before, STEM faculty operate in a MSP team environment, making it difficult to tease out their individual contributions. A compromise is to make a logical argument to supplement the empirical evidence: If STEM faculty play a significant role in the project, then they may have contributed to the observed effect or lack of effect.

Second, our study highlights the importance of a genuine collaboration among K-12 teachers and STEM and education faculty in addressing the challenges in STEM education. Because most of the IHEs in the MSP are research universities and the participating STEM faculty are either tenured or on a tenure track, the findings are limited to these IHEs and faculty. The potential for STEM faculty involvement can be much larger. Some may question whether MSP was targeting the wrong IHEs because of the priority given to research at universities, where STEM faculty is less likely to be interested in K-20 reforms. In contrast, STEM faculty from liberal arts colleges and regional state universities may be more inclined to engage in such efforts because they are more committed to teaching and learning, are more likely to reach out to K-12 teachers, and are recognized and rewarded as part of their mission. Others argue that the funding agencies should target a different type of STEM faculty, such as those who are not on a tenure track because the pressure for tenure and promotion poses barriers to involvement in K-20 reforms among tenured and tenure-track faculty.

Importantly, the landscape of IHE faculty is changing rapidly with fast expansion of nontenure-track faculty and part-time faculty (Schuster & Finkelstein, 2006). According to the Integrated Postsecondary Education Data System Fall Staff Survey for 2003, 34.8% of all full-time faculty are off-track faculty, and they represent 58.6% of all newly hired full-time faculty. In addition, part-time faculty already account for half of the academic workforce. It is important to note the marked differences within the system. Research and doctoral institutions and the more selective liberal arts colleges, while increasingly resorting to "contingent staff," still retain a large majority of full-time tenured or tenure-track faculty. Nevertheless, without the pressure of obtaining tenure by research and publications, nontenure-track faculty members may become a resource that can be tapped in the future.

Conclusions

The report provides good news, bad news, and uncertain news. The good news comes from participants. K-12 teachers reported benefits from improved approaches to teaching and learning, increased knowledge of subject matter content, and increased confidence both as teachers and as colleagues with IHE faculty. The STEM faculty also benefited from new ideas about teaching and learning, insights into education research, more knowledge of the K-12 education system, and a broader understanding of education overall. The value of collaboration and teamwork was broadly acknowledged by all participants. The bad news continues to be that relatively few faculty members in the university STEM fields participate in MSP-related activities, few benefits extend beyond those faculties who are direct participants, and few systemic changes have been made in IHE systems, especially in the tenure and promotion policies. And finally, the uncertain news resides in the impact on student achievement. One may expect that the positive changes taking place in teachers are the intermediate outcomes that will eventually lead to improved student achievement. Tackling a problem of such magnitude may require a much longer time frame.

The study provides important implications for practice. For project directors and stakeholders who plan to tap the potential of K-20 partnership and STEM faculty, the results speak to the power of a genuine collaboration. However, change is not for the faint of heart. At the project level, both extrinsic and intrinsic incentives need to be created to engage STEM faculty. The former often involve providing stipends and release time for faculty members, and the latter often include providing professional development to faculty to enhance their understanding of K-12 perspectives and pedagogical issues, building collaborations among participants, as well as demonstrating sensitivity and flexibility to faculty needs. Two of the major barriers that projects are often confronted with are the traditional tenure and promotion structures and faculty perceptions about the differential status associated with different types of activities. Although the majority of the IHEs recognize service or outreach—the terms are that often used to characterize MSP involvement—such activities are generally considered to be a distant third in priority after research and teaching. In order to change the tenure and reward policies and culture, universities are encouraged to elevate the status of service, or to redefine scholarship to include teaching, discovery, integration, and application of knowledge.

Genuine collaboration also requires participants to learn to work together. We found that STEM faculty's working relationships with other participants such as education faculty, K-12 teachers, and teacher leaders are critical not only to making MSP a more positive experience for participants, but also to the overall success of MSP projects.

A powerful implication for university STEM faculty is that when faculty deepen teachers' knowledge, teachers are not the only beneficiaries, the faculty themselves gain as well. In other words, if a STEM professor is seeking new approaches for working with undergraduates in his/her own classroom, a good way to discover and practice such strategies is to work with K-12 teachers in some intensive way, such as a summer institute. Based on our five years of research data, the faculty member will work very hard, collaborate with like-minded peers and teachers, and reap many professional and personal benefits.

To a large extent, the study can be regarded as a stimulus for thought, reflection and discussion than offering any conclusive results. NSF believes that the emphasis on STEM faculty engagement is the most distinguishing feature of MSP. Proponents who are looking for a silver bullet to solve STEM education woes will be slightly disappointed at the results. However, opponents who think STEM faculty are irrelevant in the picture will find their criticisms are not substantiated either. What we have gained from this investigation is a better understanding and appreciation of the complexities and the challenges ahead. Although we see a meaningful role for STEM faculty, we also recognize that tackling the challenges requires systemic efforts and improved capacity from the whole community of K-12 teachers, administrators, IHE education faculty, students and parents, and policymakers.

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[1] Comprehensive partnerships implement change across the K-12 continuum in mathematics, science, or both; targeted partnerships focus on improved student achievement in a narrower grade range or disciplinary focus in mathematics and/or science; and institute partnerships develop mathematics and science teachers as school- and district-based intellectual leaders and master teachers.

[2] Because the numbers represent the survey respondents, they are slightly smaller than the counts provided by the MSP projects through the IHE institution survey, suggesting that about 900 STEM faculty were involved annually.

[3] The SDR gathers information from individuals who have obtained a doctoral degree in a science, engineering, or health field. The SDR is conducted every two years and is a longitudinal survey that follows recipients of research doctorates from U.S. institutions until age 76.

[4] MSP Institute projects are not required to report student achievement data.

Measurement Instruction in the Context of Scientific Investigations With Diverse Student Populations

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The purpose of this study was to investigate the impact of a hands-on science curriculum, which integrates mathematics and supports English language development, on third-grade students' mathematics achievement—specifically the measurement subscale of the statewide assessment. The data drew from a larger five-year research and development project consisting of reform-based science curriculum units and teacher workshops designed to promote effective science instruction while integrating mathematics and supporting English language development. The third-grade curriculum places a strong emphasis on measurement skills in the context of science inquiry. The third-grade students' performance on the measurement subscale of the statewide mathematics assessment in the treatment schools was compared with that of comparison schools using a hierarchical linear model. Students at the treatment schools performed significantly higher than students at the comparison schools. The results provide evidence that an integrated approach to mathematics and science instruction can benefit diverse student groups.

In recent years, the disappointing results of U.S. students on national and international mathematics assessments have raised questions about the effectiveness of the U.S. educational system, specifically mathematics educational practices. Comparisons between U.S. students' achievement and the achievement of students abroad create an urgent need to improve mathematics instruction. An item analysis of third- and fourth-grade students' responses on the 1999 Trends in International Mathematics and Science Study revealed that U.S. students scored below the international average on the measurement, estimation, and number-sense strand (Taylor, Simms, Kim, & Reys, 2001).

Within the United States, persistent achievement gaps among demographic subgroups highlight the need for effective mathematics instruction. The 2005 National Assessment of Educational Progress (NAEP) indicated that although minority student performance significantly increased during recent years, gaps in mathematics achievement levels still remained between White students and Hispanic and Black non-Hispanic students (National Center for Education Statistics [NCES], 2005). These results emphasize the importance of creating equitable learning environments for increasingly diverse student populations in the nation.

Although several reform documents have emphasized the benefits of integrating mathematics and science instruction (National Council of Teachers of Mathematics [NCTM], 2000; National Research Council [NRC], 1996), there have been relatively few research studies examining the impact of integrated instruction on student achievement. The purpose of this study is to examine the impact of an integrated mathematics and science curriculum on measurement concepts as measured by the statewide mathematics test among diverse groups of third-grade students.

Literature Review

Developing Measurement Sense

According to the *Principles and Standards for School Mathematics* (NCTM, 2000), students in grades 3–5 should understand measurable attributes such as length, weight, volume, temperature, and time. Students should be able to choose the appropriate tools and units for measurement tasks. Instruction should provide a variety of concrete experiences so that students can develop understanding of measurement concepts in both the customary and metric systems.

Taylor et al.'s (2001) analysis of metric measurement instruction in elementary school revealed that these topics were treated in a superficial manner and focused primarily on units of length. Students were generally not provided with opportunities to explore metric measures and to develop meaningful connections between the customary and metric systems. Battista (2007) found that many traditional curricula taught procedures too early without offering opportunities for students to develop an understanding of the underlying concepts. Grant and Kline (2003) emphasized the importance of a classroom environment that provided opportunities for students to

engage in meaningful measurement tasks and argumentation between peers.

Science as a Context for Learning Mathematics

The use of context in the teaching and learning of mathematics has been a major focus of the reform movement since the early 1990s. In a traditional classroom, students are likely to think of mathematics as a collection of meaningless rules and procedures, even if they experience reasonable success (Gutstein, 2003). However, with reform-oriented curricula, students are being asked not only to provide a correct solution but also to understand the meaning of the solution (Martinez & Martinez, 1998). The emphasis has shifted from mastery of superficially learned skills to depth of understanding.

Support for the integration of mathematics and science instruction can be found in national reform documents including the *Principles and Standards for School Mathematics* (NCTM, 2000) and the *National Science Education Standards* (NRC, 1996). The provision of meaningful tasks in problem-solving situations allows students to gain insight into the relevance of school learning to their daily lives (Hasselbring & Moore, 1996). Meyer, Dekker, and Querelle (2001) suggest that such tasks motivate students to explore mathematics and provide a means for developing greater understanding.

Diversity

Reform curricula seem to be a significant step toward equity as achievement gaps appear to be narrowing as compared with traditional curricula (Schoenfeld, 2002). However, schools implementing reform curricula may be faced with multiple obstacles. Often the schools with the greatest need for high-quality curriculum materials are the least likely to receive them due to the financial constraints of high-poverty schools (Rousseau & Powell, 2005). Reform-oriented curricula are often implemented in less than ideal circumstances by teachers who lack training and are not committed to implementation (Boaler, 2002).

Effective teacher preparation for working across racial, ethnic, cultural, and social class boundaries remains a problem (Murrell, 1991). The use of relevant contexts that take into consideration students' home language and culture provides meaningful learning opportunities (Lee & Luykx, 2006). Professional development should remain a high priority in enabling teachers to accomplish the goals of mathematics reform with diverse student populations.

Research Questions

Meaningful instruction has become increasingly important as U.S. schools are faced with the challenging task of meeting the learning needs of diverse student populations, including English language learning (ELL) students. This study examined the impact of an integrated mathematics and science curriculum on third-grade students' understanding of measurement concepts. The treatment consisted of a curriculum and teacher workshops, both of which integrated measurement concepts and skills in the context of science inquiry while supporting English language development. The study examined the following research questions:

1. Do children who participate in the treatment outperform students who are taught using a traditional approach on the measurement strand of statewide mathematics assessment?
2. Does the treatment have differential effects among diverse student groups on the measurement strand of statewide mathematics assessment?

Methods

Research Setting

The study takes place in a large urban school district in the Southeastern United States with a diverse student population. During the first year of the larger five-year research (2004–2005), the ethnic makeup of the student population in the school district was 60% Hispanic, 28% Black non-Hispanic (including Haitian and Caribbean Islanders), 10% White Non-Hispanic, and 2% Asian or Native American. Across the school district, 72% of elementary students received free or reduced-price lunch programs, and 24% participated in English for speakers of other languages (ESOL) programs.

Schools were invited to participate in the larger research based on three criteria: (a) percentage of ELL students (predominantly Spanish- and/or Haitian Creole-speaking students) above the district average at the elementary school level (24%), (b) percentage of students on free or reduced-price lunch programs above the district average at the elementary school level (72%), and (c) school grades of primarily C or D according to the state's accountability plan.

At the time when schools were invited to participate, there were 206 elementary schools in the district, 33 of which met all three criteria. Of these schools, 15 schools expressed a desire to participate in the research. In an effort to select schools that were representative of typical elementary programs, seven schools were selected that were currently not part of any additional interventions. At the end of the first year of the study, one of the schools decided not to continue with the intervention. Therefore, this study included six treatment schools participating in all three years of the third-grade intervention for this

study. Three of these schools served predominantly Hispanic students, and the remaining three schools served predominantly Black non-Hispanic students.

Comparison schools were selected from the pool of the 206 elementary schools in the school district based on the same three criteria described above by using a hierarchical cluster analysis procedure (Norusis, 2006). The data from 2003–2004 (one year prior to the larger research) for all 33 of the schools including the six treatment schools were entered into SPSS. Each treatment school was matched to a comparison school with the most similar student population in terms of percentage of ELL students and percentage of students on free or reduced-price lunch. School grades, according to the state's accountability plan and school size, were used as final considerations in the event that there was more than one possible match. This process led to the selection of comparison schools that most closely matched the treatment schools on all dimensions. Table 1 provides the descriptive statistics for the treatment and comparison schools.

Participants

Teacher Participants. Teacher participants included third-grade teachers from all six treatment schools. Teachers at the treatment schools were asked to complete a brief survey of their background information including gender, ethnicity, native language(s) spoken, educational background, and teaching experience. Table 2 presents the demographic information and professional backgrounds as reported by the teachers.

Student Participants. Student participants included third-grade students from all six treatment schools. Students were evenly distributed based on gender. The vast majority of students in the treatment were classified primarily into two ethnic groups: Hispanic and Black non-Hispanic. In terms of ESOL levels, 34% of students were not considered ESOL (native speakers of English or exited from ESOL more than two years ago), 50% of ESOL students were classified as level 5 (exited within the last two years), and 16% of students were currently classified as ESOL levels 1–4. The overwhelming majority of students were receiving free or reduced-price lunch (as an indicator of socioeconomic status). Finally, 12% of the students were classified as exceptional student education (ESE) due to various exceptionalities, excluding gifted education. Table 3 presents the demographic information for students who participated in the study.

Table 1
Descriptive Statistics for Treatment and Comparison Schools

School Status	School Number	Number of Students	Percent FRL	Percent ESOL	School Grade	School Mean Reading	School Mean Math
Treatment	1	774	91.5	21.2	C	38	40
	2	917	88.1	40.1	C	49	56
	3	970	91.3	26.3	C	45	58
	4	1053	95.9	41.6	C	45	51
	5	1171	91.3	27.2	C	45	51
	6	665	84.8	32.6	B	57	61
	M	925	90.5	31.5	—	46.5	52.8
Comparison	7	871	94.9	34.1	C	44	53
	8	706	97.0	22.9	C	38	45
	9	991	85.9	39.5	B	55	62
	10	589	78.9	31.2	B	59	66
	11	893	95.1	30.7	C	41	49
	12	985	93.4	27.1	B	49	63
	M	839	90.9	30.9	—	47.7	56.3

Table 2
Year 3 Third-Grade Teacher Demographics in Six Treatment Schools (n = 45)

Variables	Demographic Groups	*n*	%
Gender	Male	3	7
	Female	41	91
	Missing	1	2
Ethnicity	Hispanic	19	42
	Black non-Hispanic	16	36
	White non-Hispanic	7	16
	Haitian	1	2
	Asian	1	2
	Missing	1	2
Native language(s)*	English	31	69
	Spanish	14	31
	Haitian Creole	3	7
	French	2	4
	Missing	1	2
Degrees	Bachelor's	26	58
	Master's	15	33
	Specialist	1	2
	Missing	3	7

Note. * Multiple native languages could be selected.

Table 3
Year 3 Third-Grade Student Demographics in Six Treatment Schools (n = 844)

Variables	Demographic Groups	*n*	%
Gender	Male	446	53
	Female	398	47
Ethnicity	Hispanic	404	48
	Black non-Hispanic	412	49
	White non-Hispanic	18	2
	American Indian	2	<1
	Multiracial	8	1
ESOL level	0 (never in ESOL or exited*)	284	34
	1	33	4
	2	13	2
	3	30	4
	4	49	6
	5 (exited less than two years)	418	50
Lunch status	Not on FRL	86	10
	FRL	758	90
ESE status	Not ESE	740	88
	ESE	104	12

Note. * Students exited over two years are no longer classified as ESOL students.

Intervention

This study was part of a larger five-year research project consisting of reform-based science curriculum units and teacher workshops designed to promote effective science instruction while integrating mathematics and supporting English language development. Although this project involved third- through fifth-grade students, the third-grade curriculum placed a strong emphasis on developing measurement skills in the context of science inquiry. Therefore, the focus of this study was on the third-grade intervention.

Curriculum. The project uses a grade 3 curriculum that is closely aligned with state science and mathematics content standards and follows recommendations by the *National Science Education Standards* (NRC, 1996) and the *Principles and Standards for School Mathematics* (NCTM, 2000). The three curriculum units for grade 3 include the topics of measurement, states of matter, and water cycle and weather.

Teachers' guides provide content-specific teaching strategies for each lesson. Suggestions are provided for planning and implementing hands-on activities, along with cautions about what may go wrong and how to respond to such situations. Background information on the science and mathematics topics, as well as explanations on common misconceptions and learning difficulties, is provided. Additionally, each lesson includes a variety of assessment items and suggestions for ways to extend the lesson in order to further enhance student understanding.

The student book for the measurement unit includes concepts involving metric and customary measurement of length, weight, volume, temperature, and time. Each lesson begins with a list of academic vocabulary in three languages (English, Haitian Creole, and Spanish), a list of materials needed to engage in hands-on activities, and a

scenario to activate students' prior knowledge. The hands-on activities are geared toward developing an understanding of standard units of measure and benchmarks (or reference points) for estimating metric and customary measures. Students are encouraged to use various formats for recording information such as charts, tables, graphs, and written responses. Hands-on experience with measurement tools such as rulers, triple beam balance scales, and graduated cylinders offers multiple opportunities to apply measurement skills in the context of real-world applications.

The student books for the States of Matter Unit and the Water Cycle and Weather Unit promote standards-based, inquiry-driven science learning. These units are designed to move progressively along the continuum of teacher-explicit to student-initiated inquiry. Throughout these units, students apply measurement skills to engage in science inquiry.

In addition to an integrated mathematics and science approach, there is an emphasis on developing English language and literacy skills incorporated into the curriculum. Each lesson begins with a link to prior knowledge, which promotes discussion of real-world experiences related to the concepts in the lesson. The student books incorporate activities and strategies that foster reading and writing. Key mathematics and science terms are provided in English, Spanish, and Haitian Creole to support communication and comprehension. The units incorporate multiple modes of communication and representation (pictures, diagrams, and transparencies) to reinforce concepts.

Teacher Workshops. Third-grade teachers in each treatment school attended five full-day workshops on regular school days over the course of the school year. The workshops were organized around familiarizing teachers with the curriculum units as well as providing strategies for promoting science inquiry, integration with mathematics, and support for English language development. Teachers were given opportunities to work through student lessons with all of the measurement tools necessary for student investigations. Particular attention was given to potential student misconceptions about measurement and ways to deal with these difficulties as they arose in the classroom. In addition, small groups of teachers participated in practice inquiry tasks, followed by discussions of experimental design, data collection, data displays, and conclusions based on data. Teachers were asked to provide feedback on the curriculum units, teacher workshops, supplies, and the effectiveness of these components of the intervention.

Due to the high percentage of ELL students in the treatment schools, a recurrent theme throughout all of the workshops was support for English language development during science instruction. Teachers were given strategies for adapting language for various levels of English proficiency, reducing the language load required for student participation, and using multiple modes of representation (oral, gestural, graphic, and written). In addition, teachers were encouraged to promote reading and writing in the context of mathematics and science investigations by having students describe, explain, report, and draw conclusions.

Supplies. Teachers were provided with class sets of materials for each curriculum unit. For example, the measurement unit includes equipment such as rulers, meter sticks, measuring tapes, kitchen scales, bathroom scales, pan balances, measuring cups, graduated cylinders, and thermometers. This guaranteed that all students participating in the intervention had the same opportunity to complete the activities as planned.

Data Collection

Data collection involved the results of the 2007 statewide mathematics assessment, which was aligned with the state mathematics standards. Data from 2007 were selected for this analysis because this was the third and final year of teacher workshops and represented the completion of teacher training. The school district provided the deidentified results for third-grade students at the treatment and comparison schools. The results included the overall mathematics scale score as well as the raw score for each subscale within the mathematics test. Specifically, the raw score for the measurement strand was designated as the outcome variable for this analysis.

The integrated curriculum for the intervention was designed to align with the state mathematics standards; however, it was not designed to align with the statewide mathematics assessment. An analysis of the public release items from the measurement strand of the statewide mathematics assessment for the third grade revealed that all of the measurement topics are addressed by the treatment curriculum, with the exception of one question on perimeter. Several of the tools used during hands-on investigations of measurement in the integrated curriculum are pictured and referenced in the public release items, including a ruler, measuring cup, pan balance, and bathroom scale. Thus, the integrated curriculum appears to increase alignment between the district curriculum and the statewide assessment.

The mathematics assessment had a total of 40 questions for the five strands, and the measurement reporting category included eight questions. The internal consistency reliability for the 2007 administration of the statewide

mathematics assessment was found in the technical reports published by the state. The Cronbach's alpha for the total test was .90 and for the measurement subscale was .62. The internal consistency reliability for the total test was well within the acceptable range; however, the measurement subscale was below the widely accepted lower limit of .70. It is important to note that it would be mathematically difficult to achieve internal consistency reliability above .70 given the small number of eight items for the measurement subscale.

The district also provided deidentified demographic data for all students including classroom assignment, gender, ethnicity, free or reduced-price lunch status, ESE status, and ESOL level at the time the statewide assessment was administered. Unfortunately, no previous test data were available for students due to the fact that the third grade is the first year that students in this state participate in the statewide assessment test.

A review of the district-adopted mathematics textbooks and pacing guides for instruction indicated that third-grade students received instruction in metric and customary measurement concepts (including length, weight, volume, temperature, and time) prior to participating in the statewide mathematics assessment. These sources of information supported the assumption that all students at both the treatment and comparison schools were exposed to similar topics of study; however, only students at the treatment schools participated in the integrated curriculum through our intervention in addition to typical mathematics instruction prior to statewide assessment.

Data Analysis

Due to the nested nature of the data, analysis was conducted using a hierarchical linear model (HLM) developed by Raudenbush and Bryk (2002). Students were nested in classrooms, which were nested in schools, allowing for a three-level HLM. This analysis allowed the variance to be partitioned at the student, classroom, and school levels.

Variables. The outcome variable for this study was the third-grade students' scores on the measurement strand of the statewide mathematics assessment test. The student-level predictor variables included gender, ethnicity, ESOL level, ESE status, and free or reduced-price lunch status. The classroom level-predictor variables included treatment and the cross-level interactions between treatment and the student-level predictor variables. Finally, the school-level predictor variables included percent of ESOL students and percent of students on free or reduced-price lunch. Table 4 provides the descriptive statistics for all of the variables.

Unconditional Model. A fully unconditional model was created with no predictor variables specified at any level. This model included 1,527 students in 92 classrooms

Table 4
Descriptive Statistics for Variables

Variable	Abbreviation	Values	*M*	*SD*
Outcome variable				
Measurement score	MEAS	0–8	4.61	1.98
Level 1 variables				
Ethnicity	ETH	0 = Hispanic, 1 = Black non-Hispanic	.49	.50
Gender	GEN	0 = Male, 1 = female	.47	.50
ESE status	ESE	0 = Non-ESE, 1 = ESE	.14	.35
ESOL	ESL	0 = Non-ESOL, 1 = ESOL	.18	.39
Free/reduced lunch status	FRL	0 = Non-FRL, 1 = FRL	.89	.31
Level 2 variables				
Treatment	TRT	0 = No treatment, 1 = treatment	.51	.50
Level 3 variables				
Percent ESOL students	PCT ESL	19.9–40.2	28.97	5.98
Percent free/reduced lunch	PCT FRL	82.1–93.4	87.93	3.84

Table 5
Student Demographics for Treatment and Comparison Schools

Variable	Demographic Groups	n = 1,562
Gender	Male	813
	Female	714
Ethnicity	Hispanic	786
	Black non-Hispanic	741
ESE	Not ESE	1,311
	Exceptional students (not including gifted)	216
ESOL	Not ESOL or exited from ESOL	1,248
	ESOL levels 1 through 4	279
Free/reduced lunch	Not receiving free/reduced-price lunch	161
	Receiving free/reduced-price lunch	1,366

Note. Incomplete data for 35 students resulted in 1,527 students in the final analysis.

across 12 schools. Table 5 provides the demographic data for the student-level variables.

The intraclass correlation (ICC) was calculated to determine the amount of variance accounted for at each level. Estimates were calculated to determine the proportion of variance among students within classrooms, among classrooms within schools, and among schools. The equations for calculating the ICC at each level are given as follows:

$\sigma^2/(\sigma^2 + \tau_\pi + \tau_\beta)$ represented the proportion of variance among students;

$\tau_\pi/(\sigma^2 + \tau_\pi + \tau_\beta)$ represented the proportion of variance among classrooms; and

$\tau_\beta/(\sigma^2 + \tau_\pi + \tau_\beta)$ represented the proportion of variance among schools.

Results of the three-level unconditional model indicated that 80% of the variance in measurement scores was at the student level, 18% at the classroom level, and less than 2% at the school level. The lack of variance at the school level indicated that a two-level HLM that accounted for variance at the student and classroom level would suffice for this analysis.

Conditional Model. The final model utilized a two-level HLM analysis with predictor variables specified at the student level (gender, ethnicity, ESOL level, ESE status, and free or reduced-price lunch status) and at the classroom level (treatment and the cross-level interaction variables). The interaction variables included treatment by gender (TRT × GEN), treatment by ethnicity (TRT × ETH), treatment by ESOL status (TRT × ESL), treatment by ESE status (TRT × ESE), and treatment by free or reduced-price lunch status (TRT × FRL). The error term was set to zero for GEN, ESE, and FRL because the between-classroom differences were not significant. In addition, because the vast majority of students participated in free or reduced-price lunch, the FRL variable was not significant and was eliminated from the model.

Proportion of Variance Accounted for (PVAF). Finally, the PVAF in the outcome variable by each predictor variable at the student level was calculated using the following formula:

$$\mathrm{PVAF}_{\text{Level 1}} = \frac{\sigma^2(\text{baseline}) - \sigma^2(\text{fitted})}{\sigma^2(\text{baseline})}.$$

This formula allows a comparison of the baseline model (without including the variable of interest) with the fitted model (including the variable of interest). Predictor variables were removed one at a time to determine the change in σ^2. The PVAF provides the effect size for each of the predictor variables.

A similar procedure was used to determine the PVAF for each of the variables entered at the classroom level. The predictor variables were removed one at a time to determine the change in τ_{00}. The PVAF in the outcome variable (MEAS) by each classroom level variables was calculated using the following formula:

$$\mathrm{PVAF}_{\text{Level 2}} = \frac{\tau_{00}(\text{baseline}) - \tau_{00}(\text{fitted})}{\tau_{00}(\text{baseline})}.$$

Results

Students at treatment schools outperformed students at comparison schools. The mean score for students at treatment schools was 4.75 (SD = 1.97) and for students at comparison schools was 4.46 (SD = 1.99). Descriptive statistics for treatment and comparison schools are displayed in Table 6.

Male students at treatment schools had the highest mean score (4.87) followed by female students at treatment schools (4.61), female students at comparison schools (4.51), and male students at comparison schools (4.41). Figure 1 illustrates that both males and females seemed to

Table 6
Descriptive Statistics by Treatment Status

Variable	Demographic Groups	Comparison *M* (*SD*)	Treatment *M* (*SD*)
Gender	Male	4.41 (1.99)	4.87(1.95)
	Female	4.51 (1.94)	4.61 (2.02)
Ethnicity	Hispanic	4.50 (1.94)	5.07 (1.99)
	Black non-Hispanic	4.41 (2.00)	4.43 (1.94)
ESE status	Not ESE	4.66 (1.94)	4.89 (1.98)
	ESE	3.39 (1.77)	3.76 (1.78)
ESOL status	Not ESOL or exited from ESOL	4.69 (1.94)	4.91 (1.96)
	ESOL levels 1–4	3.60 (1.85)	3.89 (1.93)
Total		4.46 (1.97)	4.75 (1.99)

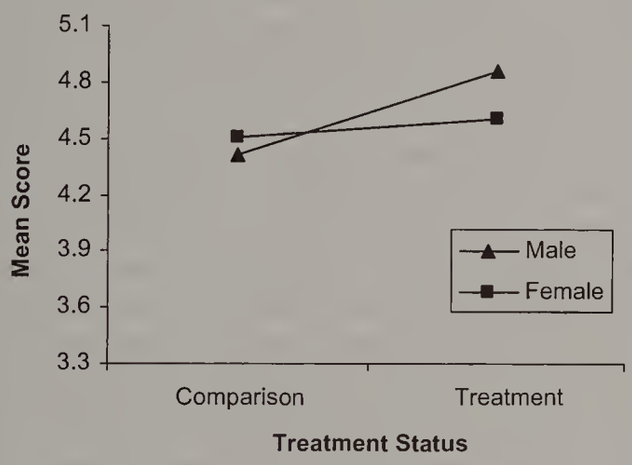

Figure 1. A comparison of means as a function of gender status and treatment status.

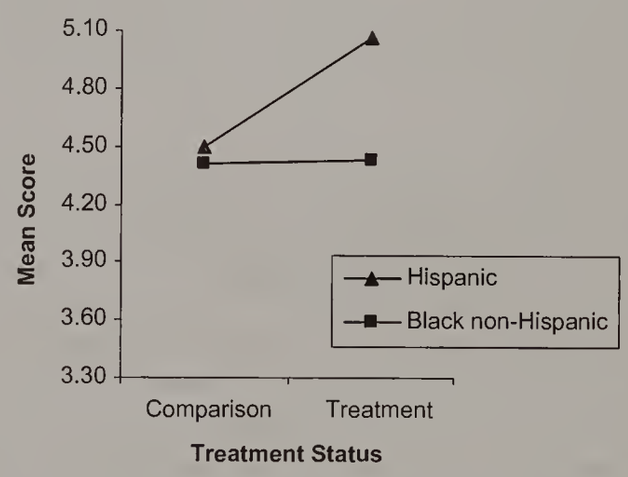

Figure 2. A comparison of means as a function of ethnicity status and treatment status.

benefit from the treatment. The difference in slopes indicates a possible interaction between treatment and gender.

Hispanic students at treatment schools had the highest mean score (5.07) followed by Hispanic students at comparison schools (4.50), Black non-Hispanic students at treatment schools (4.43), and Black non-Hispanic students at comparison schools (4.41). Figure 2 illustrates that Hispanic students seemed to benefit from the treatment more than Black non-Hispanic students. The difference in slopes indicates a possible interaction between treatment and ethnicity.

Non-ESOL students at treatment schools had the highest mean score (4.91) followed by non-ESOL students at comparison schools (4.69), ESOL students at treatment schools (3.89), and ESOL students at comparison schools (3.60). Figure 3 illustrates that both ESOL and non-ESOL students seemed to benefit from the treatment. The nearly parallel appearance of the lines indicates a lack of evidence for an interaction between treatment and ESOL.

Non-ESE students at treatment schools had the highest mean score (4.89) followed by non-ESE students at comparison schools (4.66), ESE students at treatment schools (3.76), and ESE students at comparison schools (3.39). Figure 4 illustrates that both ESE and non-ESE students seemed to benefit from the treatment. The nearly parallel appearance of the lines indicates a lack of evidence for an interaction between treatment and ESE.

Since the HLM analysis was conducted using uncentered variables, the intercept coefficient represents the mean score for students with a value of 0 for each of the variables. This means that the intercept, 4.98, represents

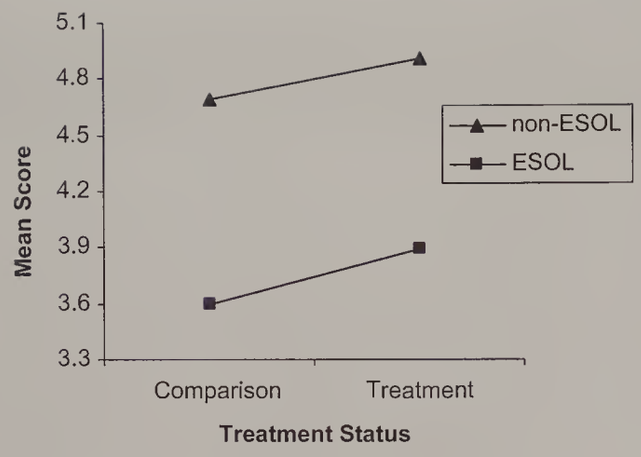

Figure 3. A comparison of means as a function of ESOL status and treatment status.

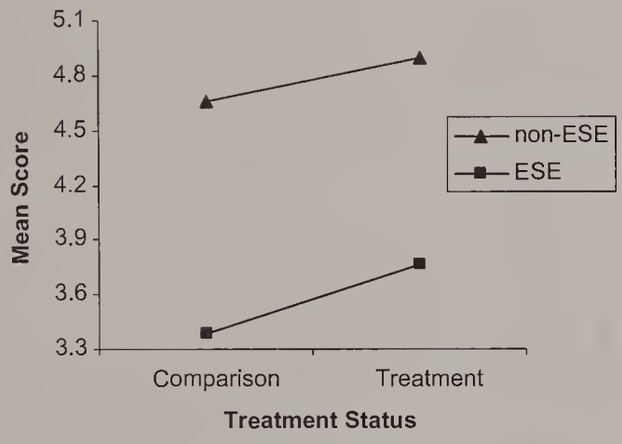

Figure 4. A comparison of means as a function of ESE status and treatment status.

the typical score of a male Hispanic student who was not classified as ESOL or ESE and did not participate in the treatment group. The coefficient for each of the variables indicates an increase or decrease of the intercept as students move from a value of 0 to 1 for that variable.

Results at the student level indicated that ESOL status (ESL) and ESE status (ESE) were statistically significant predictors of measurement achievement. The coefficient for ESL was −.82 ($p < .001$), indicating that across classrooms, we would expect an average decrease of .82 points for an ESOL student versus a non-ESOL student. The PVAF by ESL was .029, indicating that ESOL status accounted for 2.9% of the variance in students' measurement score. This represents a small effect size. The coefficient for ESE was −1.01 ($p < .001$), indicating that across classrooms, we would expect an average decrease of 1.01 points for an ESE student versus a non-ESE student. The PVAF by ESE status was .033, indicating that the ESE status accounted for 3.3% of the variance in students' measurement score. This represents a small effect size.

At the classroom level, the treatment (TRT) was a statistically significant predictor of measurement achievement. The coefficient for TRT was .55 ($p = .032$), indicating that across schools, we would expect an average increase of .55 points for students participating in the treatment. The PVAF by TRT was .089, indicating that the treatment accounts for 8.9% of the variance in students' measurement score. This represents a moderate effect size.

Finally, the remaining interaction variables, TRT × GEN, TRT × ETH, TRT × ESL, and TRT × ESE, were not statistically significant. The lack of a statistically significant interaction provides evidence that the treatment was equally effective for male and female students, Hispanic and Black non-Hispanic students, ESOL and non-ESOL students, and ESE and non-ESE students. Table 7 provides the results of the final HLM model.

Discussion and Conclusions

This study examined the impact of an integrated mathematics and science curriculum that also supports English language development on third-grade students' measurement achievement. It used an HLM analysis of students' measurement achievement scores on the statewide mathematics assessment at treatment and comparison schools.

Discussion

The primary purpose of this study was to examine whether an integrated mathematics and science curriculum, which allows students to develop measurement concepts and skills through science inquiry, would impact students' performance on statewide mathematics assessment tests (Research Question 1). Much of the existing literature describes models for integrating mathematics and science (Berlin & Lee, 2005; Huntley, 1998; Lonning & Defranco, 1997), and compromises and benefits that occur when integrating these two subjects (Frykholm & Meyer 2002; Venville, Rennie, & Wallace, 2004). The limited literature available on the implementations of integrated math and science curriculum units suggests that the context provides relevance and opportunities for students to apply the skills being learned (Davison, Miller, & Metheny, 1995; Frykholm & Meyer, 2002).

The findings of the study support the literature that an integrated curriculum, which allows students to explore mathematics in context, facilitates student understanding, and enhances achievement. In addition, the results of this study contribute to the literature by involving a large sample size (1,527 students in 92 classrooms at 12 schools) and by using high-stakes statewide assessment data. It is important to acknowledge that the moderate effect size of the treatment and the small effect size of the

Table 7
Results of Final HLM Model

Fixed Effect	Abbreviation	Estimates of Fixed Effects					
		Coefficient	*SE*	*t*	*df*	*p*	PVAF
Level 1							
Gender	GEN	−.23	.13	−1.72	1,517	.085	.008
Ethnicity	ETH	−.24	.19	−1.28	90	.205	.023
ESOL	ESL	−.82	.22	−3.77	90	<.001*	.029
ESE	ESE	−1.01	.21	−4.95	1,517	<.001*	.033
Level 2							
Treatment	TRT	.55	.25	2.18	90	.032*	.089
Treatment × gender	TRT × GEN	−.17	.18	−.92	1,517	.356	.008
Treatment × ethnicity	TRT × ETH	−.52	.27	−1.95	90	.054	.044
Treatment × ESOL	TRT × ESL	.07	.32	.21	90	.834	.000
Treatment × ESE	TRT × ESE	−.26	.29	−.88	1,517	.377	.000

* $p < .05$

cross-level interactions must be considered with caution given the relatively large sample size.

The second purpose of this study involved an examination of cross-level interactions between treatment status and student-level variables to determine whether the treatment had differential effects among subgroups of diverse student populations (Research Question 2). Recent NAEP results indicate that achievement gaps in mathematics persist among demographic subgroups based on gender, ethnicity, socioeconomic status (SES), and ESOL status (NCES, 2007). Previous studies comparing traditional and reform-based mathematics curriculum have shown the potential to narrow the gaps (Carroll, 1995; Riordan & Noyce, 2001).

In this study, the treatment appeared to benefit Hispanic students more than it did Black non-Hispanic students. The school district, however, does not identify subgroups of the generic Black non-Hispanic category including African Americans, Haitians, and Caribbean immigrants, among others. Furthermore, the school district does not identify the students' home languages separately from the ESOL status. Because of this confounding of the variables of ethnicity, home language, and ESOL status, it is difficult to interpret the nearly significant interaction of ethnicity and treatment status. The study points out the need to disentangle these demographic variables as well as inherent limitations of any study using existing data sources.

High-quality curricula are essential in implementing mathematics education reform with diverse student populations. Too often, the schools with the greatest needs are least likely to receive high-quality curricula due to financial constraints (Rousseau & Powell, 2005). In addition, reform-based curricula are often implemented under poor circumstances (Boaler, 2002). In this study, the provision of a high-quality integrated curriculum, teacher professional development, and the provision of all necessary supplies were critical for successful implementation of the integrated curriculum. These findings provide evidence of the essential components for successful implementation of a reform-based curriculum that resulted in a positive impact on student achievement.

It is important to further explore the potential of this curriculum in narrowing achievement gaps among demographic subgroups of students who traditionally do not perform as well as their mainstream counterparts. Due to the limited number of White non-Hispanic students in this study, it was impossible to determine whether the curriculum would have the potential to narrow mathematics achievement gaps among ethnic groups. In addition, interpretation of any findings with respect to ethnicity should be given careful consideration due to the difficulty of disentangling ethnicity from other variables such as home language, ESOL status, and socioeconomic status. Further studies could examine these demographic variables in a conceptually sound and methodologically rigorous manner.

Conclusions

Students who participated in the treatment group outperformed students in the comparison group (Research Question 1). This key finding indicates that students who learned measurement concepts and skills in the context of science inquiry experienced greater success on statewide assessment items than students who did not learn measurement in context. The treatment made a significant impact on students' learning of measurement. The emphasis on English language development through the provision of key vocabulary in three languages (English, Spanish, and Haitian Creole) and the use of various language support strategies may be crucial in developing student understanding with diverse student groups, especially ELL students, in these schools. In addition, the provision of supplies supported the hands-on measurement experiences in the curriculum, which fostered meaningful learning opportunities in classrooms that often lack the resources to promote hands-on, inquiry-based learning.

Another key finding was the lack of interaction between the treatment and each of the student-level variables (Research Question 2). Comparisons made between the treatment and comparison groups based on gender, ethnicity, ESOL status, and ESE status indicated that the vast majority of students appeared to benefit from participation in the treatment. The lack of significance of the interactions indicates that the treatment did not appear to have differential effects for diverse student groups. The nearly parallel growth among ESE and non-ESE students as well as ESOL and non-ESOL students indicates that ESE and ESOL students participating in the treatment kept up with their peers in terms of growth.

Although the larger research and development project is aimed at promoting effective science instruction, particularly among English language learners, this study examines the secondary impact of the intervention on students' developing measurement concepts. Students in the treatment group outperformed students in the comparison group on statewide assessment items. Furthermore, there did not appear to be any differential effects among diverse student groups. The overall positive impact on students' measurement achievement across diverse student groups indicates that the integrated curriculum had a positive impact on student achievement. These results demonstrate the benefits of learning measurement in the context of science inquiry for diverse student groups. Effective approaches to developing and implementing a high-quality mathematics curriculum that benefits all students are critical for reaching the goal of high-quality mathematics instruction for all students.

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Motivation of Latina/o Students in Algebra I: Intertwining Research and Reflections

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Latinas/os, the largest and fastest growing minority ethnic group in the United States (inipels research that focuses on the education of Latinas/os and the need to reduce the achievement gap that persists between Latinas/os and other groups. Such research has gained in popularity; however, it is still very limited. I use my teaching experience with Latina/o students to highlight the need to motivate Latina/o students in Algebra I, a gatekeeper course for many minority students. In addition, also included are several factors affecting Latina/o students' motivation to learn. The call is urgent and researchers and teachers must pay close attention to the mathematics education of Latina/o students and to the positive consequence on the social and economic welfare of America.

Latinas/os are the largest ethnic group and the fastest growing minority in the United States (Gándara & Contreras, 2009). Within a 10-year span from 1990 to 2000, the Latino population increased from 22.4 million to 35.3 million, compared to an increase of only 13.2% for the total U.S. population (U.S. Department of Education, 2003). Additionally, between 2000 and 2006, Hispanics accounted for one-half of the nation's growth and the Hispanic growth rate (24.3%) was more than three times the growth rate of the total population (6.1%). According to census projections, the Latina/o population will increase from 47.8 million in July 1, 2010 to 102.6 million by July 1, 2050 (U.S. Census Bureau, 2000).

Research that focuses on the education of Latinas/os and the need to reduce the achievement gap that persists between Latinos and other ethnic groups is limited. However, the impact that the Latina/o population growth has and will have on the social and economic welfare of the United States has brought much needed national attention to narrowing the gaps. Researchers and other education stakeholders (Brown, 2009; Gándara & Contreras, 2009; Hondo, Gardiner, & Sapien, 2008; Swail, Cabrera, & Lee, 2004, Taningco, 2008) have highlighted the need to educate this fastest growing population of students. Henry Cisneros (2009), former secretary of housing and urban development and former mayor of San Antonio, recently edited the book, *Latinos and the Nation's Future*, which looks at the population growth of Latinas/os and its impact on American life. Overall, there is a gap in achievement, but in particular, the mathematics gap is most often noted and considered most crucial.

Gándara and Contreras (2009) state in their recent book, *The Latina/o Education Crisis*, that Latinas/os, when compared to other students, are more likely to change schools, attend crowded, segregated and isolated schools, have inexperienced and/or underprepared teachers, have unequal access to gifted programs and/or college preparatory curriculum, honors and Advanced Placement (AP) classes, and more likely be placed in low, noncollege-bound tracks. These conditions may affect the motivation of Latinas/os in high school. As a result, researchers and educators across the country and throughout time have asked the question, "what factors contribute to the gaps in the opportunities to learn (Flores, 2007) for Latina/o students?"

Understanding the motivation of students is critical to good teaching and is a major concern for many teachers. Motivation, in general, encompasses something that is "natural" (Kohn, 1999) and "concerns energy, direction, persistence and equifinality—all aspects of activation and intention" (Ryan & Deci, 2000, p. 69). As Jaime Escalante (as portrayed by Edward James Olmos in the movie *Stand and Deliver*) states, motivation is the "*ganas*"—the desire to learn for learning sake. Motivation is often categorized in two ways—intrinsic and extrinsic—and is fundamental for students' willingness to engage in the learning process. Educational researchers (Deci, Vallerand, Pelletier, & Ryan, 1991; Kohn; Lumsden, 1994) agree that motivation is an inner drive that everyone possesses. Students are intrinsically motivated when they have a desire to be taught or to participate in an activity purely because they need or want to know more about something. Students are extrinsically motivated when they undertake a task purely for the sake of attaining a reward or for avoiding some punishment (Dev, 1997).

Teachers generally focus on motivation as it relates to academics in the content areas, whereas student academic motivation focuses on the students' desire to participate in the learning process (Lumsden, 1994). Teachers often try to provide students with reasons for wanting to get involved in their own content learning. Consequently, teachers' plans often include such things as activities,

projects, and tasks that they consider strategies that increase students' motivation. In their book, Berliner and Biddle (1995) claim, "What determines how effectively students will learn isn't how motivated they are. It's how they are motivated" (p. 126).

Making Use of Motivation Theories for Latinos in Algebra I Context

Motivation Theories

The gaps in opportunities to learn for Latinos in Algebra I have prompted researchers and educators to examine theories of motivation. It is useful at this point to briefly describe academic motivation theories that particularly focus on student motivation. Among these theories are the self-determination theory (SDT), the attribution theory, the expectancy-value theory, the social cognitive theory (SCT), and the goal orientation theory.

The SDT focuses on students' interest in learning, valuing of their education, and their confidence in their own capacities and attributes (Deci et al., 1991). The attribution theory's (Heider, 1958) basic principle considers students' influences on their success or failure. For example, people, in general, attribute success internally to ability or intelligence and the success of rivals to external attributes such as "luck." According to the expectancy-value theory (Fishbein & Ajzen, 1975), a learner's motivation is determined by the amount of success expected, which depends on the amount of value placed on the goal to be reached or task to be performed. The SCT (Bandura, 1977) describes students' learning in terms of the interrelationship among their behavior, and current environmental and personal factors. The goal-oriented theory (Dweck & Leggett, 1988) suggests that a learner has one of two orientations that guide their activities, thoughts, feelings, and even performance: mastery (learning) goal orientations and performance goal orientations. Students with mastery goal orientations are more likely to seek out challenges and take difficult courses. Students with performance goal orientation focus on getting good marks and taking easy courses.

Knowing about academic motivation theories is essential for teachers because Latinas/os students "who are more motivated learn more [and] . . . those who learn more become more motivated" (Richmond, 1990, p. 194). As a Latina teacher of Latina/o students for almost 30 years, I argue that teachers should try to incorporate a variety of motivational theories in their lessons to enhance Latinas/os' learning. This is essential because students may be more motivated under one particular theory than another. Teachers' beliefs of one particular theory and/or their preference in using one theory over another often reflect the particular theory's notion in their teaching. However, understanding that other presumably more effective motivational theories may be used in their teaching may assist teachers in motivating more of their students. Knowing about and using different motivational theories, in turn, may positively influence Latinas/os' motivation. Importantly, it is Algebra I that remains the most commonly acknowledged gatekeeper in the high school curriculum.

Latina/o Students in Algebra I

Some reform movements, for example the "new math" of the 1960s, have attempted to change algebra instruction. Nevertheless, changes are not clearly visible in many present day classrooms. In Algebra I classrooms, not much has changed in the last 40 or so years in how algebra concepts are taught. Traditionally, Algebra I encompasses "a narrow range of by-hand skills for transforming, simplifying, and solving equations—most divorced from any natural context" (Williams & Molina, 1998, p. 41). Such instructional strategies, however, are not what are needed in today's technological world to prepare Latinas/os for the academic world or the business world. More importantly, in present-day Algebra I classrooms, where Latina/o students are struggling with the language and the concepts taught, are not culturally relevant for the students, we need appropriate strategies. In addition, these strategies should also attend to today's technological demands.

According to a recently published U.S. Department of Education report (2008), the sharp decrease in mathematics achievement in the United States begins as students reach late middle school, where, for more and more students, algebra course work begins. Mathematics, in general, but algebra in particular, is considered a gatekeeper to higher education (Evan, Gray, & Olchefske, 2006; Johnson, 2010; Swail et al., 2004; U.S. Department of Education). In fact, a great number of young adolescents encounter difficulties with numerous aspects of mathematics, and many observers of educational policy see algebra as a central concern (U.S. Department of Education, p. xii). Such conditions are more prevalent in Latina/o students whose curriculum often fails to prepare them to succeed or excel in high school and beyond (Gándara & Contreras, 2009). Moreover, the more ill-prepared Latina/o students feel, the less motivated they become. This may be why Latinas/os graduate from high school without deep conceptual understanding of algebra concepts.

Algebra has emerged as a fundamental apprehension for many students. This important concern is critical especially for Latinas/os, for it is a sure first step to later achievement in higher education. Thus, students need to master algebra in order to take more advanced mathematics course work in high school (Evan et al., 2006). A report by the Educational Policy Institute found that

> Latinos need to be enrolled in and master Algebra I no later than the ninth grade in order to reap the benefits of high mathematics achievement on postsecondary persistence. Latinos who take more than three years of mathematics beginning with Algebra I have a higher probability of graduating from college than those who take fewer than three courses. (Swail, Cabrera, Lee, & Williams, 2005, p. III-3)

In particular, the American Institutes for Research (2006) find that "proficiency in algebra by ninth grade is the key for student access to advanced-level high school courses, high school graduation, and college attendance and completion" (p. 25).

Latinas/os' Motivation in Algebra

There are several factors related to why Latina/o students may be disinterested in mathematics and may not be motivated to learn in an Algebra I class. From personal experience, I noted several factors that affected Latina/o students' motivation to learn. Things such as content prerequisites, predisposed attitudes toward the subject, mathematics anxiety, placement in heterogeneous classrooms, traditional content pedagogy, and teachers' attitude and comfort level in the content and/or their understanding of Latina/o students figure prominently. In addition, other factors may influence the motivation of Latina/o students in mathematics, in general. While these factors are not necessarily unique to Latina/o students, they were observed in my classes repeatedly.

Content Prerequisites

During my years as an Algebra I teacher, I became aware of a vast number of Latina/o students enrolled in Algebra I who were often ill prepared and regularly encountered difficulties in this course because of weak, required prerequisites of basic mathematical knowledge, necessary for success (Gándara, 2006b). Most, if not all, mathematics is sequential; acquiring new mathematical concepts depends on the understanding of earlier skills and concepts. Therefore, if students do not understand important concepts introduced early in the semester or in prior years, they will certainly not understand more abstract concepts presented toward the end of the semester. Algebra I is a course where abstract concepts are introduced. Thus, if students do not grasp the first lessons in the course, they will have trouble and subsequently will feel lost toward the end of the course. Another observation from my experiences in teaching Algebra I classes was that Latina/o students in my classes lacked proficiency and understanding of basic number sense, fractions, geometry, and measurements, which are necessary and essential parts of any high school mathematics course (U.S. Department of Education, 2008).

Students' Predisposed Attitudes Toward Mathematics

Another factor often affecting Latina/o students' motivation is their predisposed attitudes and sometimes pessimistic beliefs about mathematics (Ramirez, Taube, & Taube, 1990). Attitude is an important factor that influences participation and success in mathematics, and therefore motivation. Students may enter the Algebra I classroom with negative beliefs about the subject, high levels of mathematics anxiety, and low levels of motivation to learn. They may have had ineffective teachers in the past or experienced failure upon failure. They have ingrained in their minds such attitudes as the "I hate math" attitude or the "I do not see why I have to learn this . . . I will never use it" attitude. Andres, a ninth-grade Algebra I student, stated to me in English and Spanish, "I really, really hate math . . . *no me gusta porque no le entiendo.*" In effect, he clearly states that he hates mathematics and does not like it because he does not understand it. Maria, another of my students, expressed a similar negative attitude toward mathematics when she said, "*A mi no me gustan los numeros*" (I do not like numbers).

Mathematics Anxiety

An additional reason for students' lack of motivation and dislike of mathematics is anxiety for the subject (Tobias, 1993). Mathematics anxiety, a common situation in many Algebra I classrooms, occurs when students begin to experience great apprehension regarding mathematics. They may even get to the point that they "hate" and/or fear it. Students experience anxiety for a variety of reasons: They sense a lack of preparation; they are not regularly attending classes; they have or have had negative experiences with teachers or parents; or they are not able to relate mathematics to the real world. Additionally, learning mathematics well and acquiring proficiency in the subject requires students to develop the necessary critical thinking and analytical skills. However, students often lack the understanding that is required for mathematics proficiency and this many times leads to cases of mathematics anxiety.

For many students, mathematics serves no purpose in their own "real" world; therefore, they are anxious when confronted with an abstract and irrelevant topic. Teachers,

even teachers of mathematics, may be to blame. They "turn students off" to mathematics by presenting mathematics as an accumulation of numbers and symbols, without any attempt of making it relevant to the students' life. Instead, teachers should focus on the mathematics often found in the Latina/o students' culture—for example, the Aztec calendar, the pyramids, the music. Although not a focus of this paper, teachers' anxiety also affects students' anxiety.

Heterogeneous Classes

In addition to mathematics anxiety and negative attitudes, the composition of the class also influences students' motivation. A large number of Algebra I classes are a heterogeneous clustering of students of various levels of ability and motivation. It also does not help that Algebra I is a required class, so there are students with mathematical abilities from freshman to juniors and sometimes even seniors that are placed in many Algebra I classes (Brown Center Report on American Education, 2008). Such a classroom makeup alone may affect the highly motivated as well as the less motivated Latina/o students in the same class. Another former student, Keta, when asked why she never orally answered any of the questions stated, "Let the smart GT students that like mathematics answer the questions . . . *Yo no soy GT*" (She was referring to the gifted and talented students that were also in her class). Heterogeneous placement can be a positive factor, but it can also be detrimental to motivating low achieving students as well as high achievers who may be bored.

Traditional Pedagogy

Traditional teacher-directed strategies and other nonmotivating pedagogy are approaches most often used by Algebra I teachers. However, this "one size fits all" mentality does not tap all the learning styles or achievement and ability levels students possess. Traditional pedagogy often bores students, thus turning them off to mathematics, to school, and leads to thoughts of dropping out. Berliner and Biddle (1995) found that Latina/o students are often in mathematics classrooms where a low-level curriculum is designed around test-taking skills. Many more are in classrooms where teachers use worksheets-stressing drill, practice, and other "mind-numbing" (p. 306) strategies. Frequently, teachers believe that they use these strategies with their students' best interest in mind. Unfortunately, many assume that Latina/o students lack ability and are unable to achieve success in a more rigorous curriculum, and thus lower their expectations. Students like Manny and Sylvia expressed their frustration when frequently given worksheets of basic problems. Manny declared, "We don't have to think, we just write any answer and turn it in." In addition, Sylvia concurs and adds "*Es lo mismo todos los dias*" (It is the same every day), referring to the "busy work" she got from her teachers. Teachers must diversify teaching strategies and make lessons more culturally relevant to motivate Latina/o students. One effective strategy is the use of language cognates when introducing mathematics vocabulary. Another is to involve students in hands-on projects using cooperative groups. For example, one successful strategy would be to have students work in groups on a problem-solving or inquiry-based project such as the tetrahedral kite activity. The tetrahedral kite activity demands that students work in groups to use algebraic and geometry concepts to construct kites.

Teachers' Attitude and Comfort Level in the Content

Teachers are important for student success. Their attitude and comfort level in the content they have to teach is most significant. Recently, the U.S. Department of Education (2008) in the National Mathematics Advisory Panel report found that culturally and linguistically diverse students' success in mathematics highly depends on their classroom teacher. In addition, it reported 62% of teachers rated "working with unmotivated students" as the "single most challenging aspect of teaching Algebra I successfully" (p. 9). Additionally, many mathematics teachers feel unqualified to work effectively with minority students in class. They may fear that they do not know how to reach them. Some even hold lower expectations for them, present simplified lessons, and spend a great amount of time focusing on basic skills (Johnson, 2010).

I argue for the need to provide teachers with professional development in content areas to develop their confidence and therefore their willingness to plan interactive, culturally responsive, and relevant lessons in Algebra I.

Teachers' Understanding of Latina/o Students Culture

Teachers' understanding of Latina/o students is another important factor that affects students' academic motivation (Valenzuela, 2002). Teachers are the most important and critical resource for students (Gándara & Contreras, 2009; Sheets, 2005). Research has shown a correlation between the quality of teachers and the achievement of their students (Wenglinsky, 2004). According to Gándara and Contreras, highly qualified teachers, especially those well trained to address Latina/o students' learning needs, are an important resource. The message is clear—the quality of instruction along with having high expectations for Latina/o students has a tremendous impact on the academic achievement of Latinas/os. Nevarez and Rico (2007) noted that "Culturally competent teachers are a benefit to all students, but particularly to Latinos" (p. 8).

From my perspective, I see that teachers must be more than just "good" teachers; they also have to know about the students in their classroom. They must strategically plan lessons that appeal and pique their students' interest. Johnson (2010) agrees that teachers of Latina/o students in mathematics classrooms need to be very familiar with "their (students') sociocultural, cognitive, academic, and linguistic assets" (p. 21) as well as their individual mathematical needs. School leaders must "encourage their teachers to engage in practices that disproportionately benefit their minority students" (Wenglinsky, 2004, p. 1). Culturally competent teachers should know their students and should also understand and acknowledge the important role culture plays in their educational success.

Other Factors

Finally, Latina/o students have other barriers that they must address in order to be successful in Algebra I classrooms. Nonsupportive parents, for instance, pose a significant barrier for some Latina/o students. However, oftentimes, it is not that parents do not want to be supportive; it is that oftentimes they cannot be. For example, even though many Latina/o parents support and value education highly, many do not or cannot offer the needed financial support (Martinez, DeGarmo, & Eddy, 2004). In the case of my student Diana, who had eight siblings and whose parents valued education and provided as much support as they could, asked for an extension to turn in her semester project because the family could not afford the needed items until her father's payday. The low social economic status of students of any ethnic group is a barrier.

In addition, many Latina/o parents may have gender-biased expectations and stereotypes; they may be against asking for education loans, may misallocate family funds into noneducation priorities, or may pressure students to earn an income right out of high school. Other barriers such as the racial/ethnic discrimination that is still very common and the lack of mentorship and role models, who show Latina/o students that higher education is an option, contribute to the difficulties Latinas/os have to deal with (Taningco, 2008). It is obvious that Latinas/os face enormous challenges and face an "upward struggle" at every level (Swail et al., 2004, p. 32).

Conclusion

Some present-day reform efforts sporadically address the educational needs of Latina/o students, and some have modestly reduced the achievement gap that exists between ethnic groups. However, these efforts have not lessened the urgency of the educational attainment of Latinas/os.

Gándara (2006a) states in the report *Fragile Futures: Risk and Vulnerability Among Latino High Achievers* that even high-achieving Latinas/os' academic futures are "hanging by a thin thread of hope" (p. 3) and can be characterized as "fragile" (p. 5). The motivation of Latina/o students in algebra class is a serious issue because the underrepresentation of Latina/o students in advanced math courses bears serious implications for American society (National Research Council, 2001; U.S. Department of Education, 2008).

The application of motivation theories, for example the goal orientation theory and the SDT, offer a viable and essential lens by which we can examine and address gaps in opportunities to learn. First, mastery becomes the most desirable for goal orientation for learners and teachers to consider. Inevitably, the dilemma of content prerequisites will be challenged if we shifted toward mastery of content in contrast to performance of basics skills. Clearly, the mastery of the mathematical concepts creates a more fundamental and deeper understanding that is more useful in higher level mathematics. Consequently, the dilemma of heterogeneous classrooms dissipates once a mastery paradigm becomes prevalent. Second, the SDT also provides a salient lens by which we can examine current mathematics instruction. In emphasizing the value of education and students' existing capacities and attributes, mathematics educators would lessen the negative predisposed attitudes toward Algebra I. As a result, students' mathematics anxiety may also be reduced. Finally, while utilizing self-determination and goal orientation theories to moving students toward greater achievement in Algebra I, teachers' own pedagogical practices can also benefit from change. In altering traditional teaching practices, attitudes, and comfort levels of their own content knowledge and understanding the linguistic and cultural assets of Latino students, teachers greatly benefit from their use of motivational theories. Mathematics educators could readily identify goal orientation and SDT as possible ways to address the challenges noted in these reflections.

Today, Latinas/os make up almost half of the student public education school-age students, but as a whole, they have the lowest educational attainment of students of color. Unfortunately, this is especially true with high-achieving Latina/o students (Gándara & Contreras, 2009). It is time for teachers and researchers to focus on Latina/o students' motivation in Algebra I classes. This paper is a call for teachers and all education stakeholders to consider motivational theories in addressing the motivation of Latina/o students in Algebra I classes. Without success in Algebra I classes, the underrepresentation of Latina/o

students in higher education institutes, in science, technology, engineering, and mathematics fields, and in schooling in general will persist. Researchers and educational stakeholders need to pay close attention to the mathematics education of Latinas/os students and the positive consequence of strengthening their education.

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Comparative Analysis of Two Inquiry Observational Protocols: Striving to Better Understand the Quality of Teacher-Facilitated Inquiry-Based Instruction

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With inquiry being one of the central tenets of the national and most state standards, it is imperative that we have a solid means to measure the quality of inquiry-based instruction being led in classrooms. Many instruments are available and used for this purpose, but many are either invalid or too global. This study sought to compare two observational protocols: Electronic Quality of Inquiry Protocol (EQUIP) and Reformed Teacher Observation Protocol (RTOP) with regard to reliability, validity, and utility associated with inquiry-based instruction. Analyses included studying item reliability, inter-rater reliability, factor analysis, correlation, and multiple regression of protocol items within the instruments and between the instruments. General findings suggest that both instruments have high item reliability and are effective measures in both math and science classrooms; EQUIP showed higher inter-rater reliability and seems to be more valid for measuring inquiry-based instruction, while RTOP seems better suited for looking more globally at constructivist teaching practices. Additionally, the utility of EQUIP seems to be larger. It is useful for looking formatively at individual teaching practice, as well as studying summative teacher growth or program effectiveness. Further, because EQUIP uses a descriptive rubric instead of a Likert scale, the instrument provides immediate and targeted feedback to teachers, instructional leaders, and professional development facilitators. This feedback includes both a micro view (individual indicators) and a macro view (construct) of teaching practice.

The goal of bringing high-quality inquiry-based instructional practice into science and mathematics classrooms has continued to be central to discussions and reform efforts for the last several decades (Bransford, Brown, & Cocking, 2000; National Academy of Sciences, 2007; National Council of Teachers of Mathematics [NCTM] 2000; National Research Council [NRC] 1996, 2000; National Science Teachers Association [NSTA] 1998). Yet, success in achieving this goal has been modest and inconsistent across the country. Although definitions may vary to some degree, clear direction has been given to defining and exemplifying inquiry-based instruction (NCTM, 2000; NRC, 1996, 2000). Even though consistency can be found among many of the definitions and agreement is found in the desire for reform that includes inquiry-based instruction, the implementation is often inconsistent.

In order to achieve transformation in practice, clear, valid rubrics and/or measures are needed to track formative and summative progress. Numerous instruments are available that monitor and measure teacher effectiveness and include the following:

- Inside the Classroom Observational Protocol (Horizon Research, 2002)—focus: global view of effective classroom practice;
- Reformed Teaching Observation Protocol (RTOP) (Sawada, Piburn, Falconer, et al., 2000)—focus: constructivist classroom issues in math and science;
- Electronic Quality of Inquiry Protocol (EQUIP) (Marshall, Horton, & White, 2009; Marshall & Horton, 2009; Marshall, Smart, & Horton, 2010)—focus: inquiry-based instruction in math and science;
- Science Teacher Inquiry Rubric (Beerer & Bodzin, 2003)—focus: inquiry instruction aligned to the *National Science Education Standards (NSES)*;
- Science Management Observation Protocol (Sampson, 2004) focus: classroom management issues that support effective science instruction;
- Secondary Science Teaching Analysis Matrix (Adams & Krockover, 1999)—focus: move novice teachers toward more student-centered instructional strategies;
- Expert Science Teaching Educational Evaluation Model (Burry-Stock & Oxford, 1994)—focus:

excellence in science teaching from a constructivist framework; and

• Teacher efficacy scales (Riggs & Enochs, 1990)—focus: predict the likelihood of reform.

While each of the previously mentioned protocols has merit, two of the instruments, RTOP and EQUIP, form the foundation of this study. The selection of these two instruments was based on several factors: (1) Both of these instruments provide measures that target inquiry-based instruction in math and science classrooms; (2) both have validity studies to support their work; and (3) the other instruments were either too general (e.g., consider all elements of effective practice), too granular (e.g, consider one aspect of instruction such as classroom management), or too complex (e.g., necessary to use multiple rubrics over multiple days). Further, by attending any science education research conference, it is clear that RTOP seems to be one of the most often used instruments when studying inquiry instruction and has been seen as the leader in this area for many years. EQUIP is a valid instrument that was developed, tested, and refined during the past three years (Marshall et al., 2010). The framework for EQUIP originated from joining components of many existing frameworks in an attempt to provide a means for studying teachers' transformation toward greater quantity and quality of inquiry-based instruction (Horizon Research, 2002; Llewellyn, 2007; Sampson, 2004; Sawada, Piburn, Falconer et al., 2000).

Before proceeding, it seems important to operationalize and compare constructivism and inquiry. Constructivism, the broader of the two concepts, is characterized by an active engagement of the learner in the development of knowledge instead of a rote memorization forced upon the learner (Bransford et al., 2000; Driver, Squires, Rushworth, & Wood-Robinson, 1994). RTOP was originally constructed under the premise that constructivism is at the core of the reform movement in education, and thus the instrument attempts to measure the degree to which this occurs in math and science classrooms (Sawada, Piburn, Falconer et al., 2000). Constructivism, a psychological theory behind many student-centered instructional strategies, describes learning as a process in which individuals "create knowledge from the interaction between their existing knowledge or beliefs and the new ideas or situations they encounter" (Airasian & Walsh, 1997, p. 33). Constructivist learning theories favor instructional strategies such as inquiry over didactic instruction because proponents of constructivism argue that learning can only occur if students are given the time and the means to develop their own understandings.

Although inquiry is not the only student-centered instructional strategy, it is a critical strategy that should be part of every science classroom (Bransford et al., 2000; NRC, 1996, 2000). For clarity, we use an established definition of inquiry, set forth by *NSES*:

> Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. (NRC, 1996, p. 23)

Various nuances of inquiry are further detailed in the *NSES* (p. 175) and in other research documents and publications (Karplus, 1977; Llewellyn, 2002, 2007; NRC, 2000), but the essence of scientific inquiry is clear—students critically and systematically engage in examining, interpreting, and analyzing questions regarding the world around them, and then communicate their findings, providing convincing arguments for their conclusions. EQUIP addresses constructivism very specifically by considering only the aspects associated with inquiry-based instruction in math and science education (Marshall, 2009; Marshall et al., 2009). Despite the authors' original broader constructivist intent (Sawada, Piburn, Falconer et al., 2000), many have used and continue to use RTOP to measure the more specific aspect of constructivism, namely, inquiry-based instruction. Sawada et al. (2002), in their description of the RTOP instrument, state that the instrument is "a 25-item classroom observation protocol that is (a) standards based, (b) inquiry oriented, and (c) student centered" (p. 245). Roehrig, Kruse, and Kern (2005, 2007) used a slightly modified RTOP (to account for a preestablished curriculum) to examine high school teachers' implementation of an inquiry-based chemistry curriculum.

In an effort to critically examine both instruments, three research questions guide the analysis conducted in this project: (1) How do the RTOP and EQUIP compare in terms of providing meaningful data regarding the quality of inquiry-based instruction that is transpiring in science classrooms? (2) What is the relationship between the RTOP and EQUIP scores? (3) What is the utility of each protocol? Note that the third question is an inferential question that will be addressed after the analysis has been completed.

Methods

Participants

Researchers from two universities collaborated to collect the data for this project from middle school science teachers throughout a southeastern state. The participants in this study come from two different professional development programs. Each program provides a year of sustained intervention with a primary goal to improve the quality of inquiry-based instruction being facilitated in science and math classrooms. The interventions for both programs include two weeks of summer involvement with at least four group follow-up experiences during the academic year plus individual classroom support. In an attempt to reduce confounding variables, only middle school science teachers are included in this analysis.

Instruments and Data Collection

Fifty-two complete classroom observations were conducted with 35 different teachers. The time of each observation ranged based on school schedules (e.g., block), but the observation spanned the entire science lesson facilitated. Because lessons differ in length and are often not constrained to one period of instruction, each observation may or may not have included an entire instructional sequence where complete conceptual understanding was achieved. At the culmination of each observation, researchers completed both the RTOP and the EQUIP protocols. Even though both protocols have a qualitative portion associated with them, only the quantitative data were analyzed for this study.

RTOP. The quantitative data for RTOP include 25 data points (indicators) that are divided into three major constructs (Sawada, Piburn, Turley et al., 2000): (1) *lesson design and implementation*, (2) *content*, and (3) *classroom culture*. Content is further divided into *propositional knowledge* and *procedural knowledge*, and classroom culture is further divided into *communicative interactions* and *student/teacher interactions*. Collectively, RTOP has five distinct constructs, each composed of five indicators. Data for each item or indicator score are based on a five-point Likert scale (0 = never occurred to 4 = very descriptive). After all 25 indicators have been scored, a summative total is generated that can range between 0 and 100.

EQUIP. The quantitative data from EQUIP include 19 indicators and five different composites. The 19 indicators are divided into the following four constructs: *instruction* (five items), *discourse* (five items), *assessment* (five items), and *curriculum* (four items). After scoring each indicator, five composite scores are generated (one for each construct plus an overall score for the lesson). Each indicator and composite score can range from 1 to 4 (Level 1 = preinquiry, Level 2 = developing inquiry, Level 3 = proficient inquiry, and Level 4 = exemplary inquiry). The composite scores are based on the essence for that composite rather than on the average of all indicators in the composite.

Training of Researchers. All four researchers (two science education researchers and two graduate students) were trained to use both RTOP and EQUIP. Team A (a science education researcher and a graduate student) had been using the RTOP as their primary evaluation instrument, while Team B had been using the EQUIP as their primary instrument. Both teams were initially trained on the RTOP via a series of online training videos followed by a collaborative dialogue after viewing each video to process questions and concerns regarding the scoring of each item. Team A had been exclusively using the RTOP prior to this study had been using it to evaluate middle school and high school teachers' instruction over the year-long period. Team B had been using EQUIP to evaluate the quantity and quality of inquiry being implemented in elementary, middle, and high school math and science classrooms in the two years prior to this study, but had used RTOP prior to this time. Both teams spent an entire day working together to observe four classes and to discuss justifications for individual ratings given for teachers that were observed. The data gathered and analyzed during this collaborative day focused on improving inter-rater reliability but were not included in the data analyzed for this project. Both science education researchers had prior experience and training using the RTOP before this study, but only one had prior experience using the EQUIP. Thus, it would seem that greater inter-rater reliability would be achieved on the RTOP because of greater familiarity with the instrument as a research team, ceteris paribus.

Data Analysis

After the RTOP and EQUIP data for each observation were collected by the two research teams, the data were pooled for analysis. The following analyses were conducted on both the RTOP and EQUIP using the observation data: (1) item reliability (Cronbach's alpha) for each construct and for the entire protocol (discussed above), (2) inter-rater reliability (Cohen's kappa), (3) exploratory factor analysis using varimax rotation, (4) correlation to study bivariate comparison, and (5) multiple regression to compare items and constructs with the overall dependent lesson score. Data from this study will additionally be compared with prior results that have been published for both protocols involving reliability and validity.

Results

Item Reliability

Item reliability, measured by Cronbach's alpha (α), is summarized in Table 1. In summary, both RTOP and EQUIP have alpha scores that exceed .81 for all constructs and for the protocols as a whole. When indicators 4—*lesson encourages students to seek alternative modes of problem solving*, 6—*lesson involved fundamental concepts . . .*, 8—*teacher had solid grasp of subject matter content . . .*, and 23—*teacher was patient with students* are deleted from the RTOP total protocol, the reliability for the new 21 items actually increased slightly from .962 to .964. Generally speaking, reducing the number of items in the instrument tends to decrease the reliability. Thus, the increase in α when removing one or more items may suggest that these items are potentially problematic and need to be explored further. This will be addressed further in the discussion. Likewise, when items A1—*prior knowledge* and C4—*organizing and recording information* are deleted from the EQUIP protocol, the item reliability increases slightly from .977 to .978. These items will likewise be explored in more detail later. Regardless, the total α scales for both instruments are extremely high (.962 for RTOP and .977 for EQUIP).

Inter-Rater Reliability

To allow for calculations of inter-rater reliability, 22 observations from the entire set of 52 observations (42%) were paired observations (thus, 11 pairings). These paired observations included different researcher groupings: four pairings with science education researcher and graduate student from Program A, three pairings with the two science education researchers, and four pairings with science education research and graduate student from Program B. Cohen's kappa (κ) was used to report inter-rater scores because it eliminates the role that chance plays in determining each paired score (e.g., if an item has five choices, then there should be 20% agreement just by chance), and it equalizes the difference between five options on the Likert scale for RTOP and four options for the descriptive rubric on EQUIP. Using Landis and Koch's interpretative levels (1977), paired data for the RTOP showed a moderate level of agreement (κ = .56) with a range of .05–.95. The EQUIP data for both the total 24 items (κ = .61 with a range of .2–.95) and the five constructs (κ = .66 with a range of .20–1.0) showed substantial agreement. There is no need to look at κ scores for the RTOP composites because researchers do not commonly use these composites in an interpretive sense, and it will be shown later that the constructs do not hold together in a reliable and valid sense.

Because both RTOP and EQUIP scores are continuous data, it is not expected that reviewers would come to 100% consensus even after considerable discussion (Wainwright, Flick, & Morrell, 2003). For instance, if two reviewers see a score between 2 and 3, each may have seen slight subtle differences in the lesson that justify awarding a 2 or a 3. This does not take away from the value of the score provided. To further emphasize the closeness of inter-rater scores, for EQUIP, there were 264 possible chances for agreement. The majority did agree (even after removing chance), but none of the paired data points differed by more than one point. For RTOP, of 275 possible paired data points, 16 occurrences (6% of pairings) resulted in data points that differed by more than one point. However, a consistent pattern was not noted for these inconsistent data pairings. Specifically, they occurred between numerous reviewer pairings, and their occurrence was spread among 12 different indicators.

Table 1
Item Reliability (Cronbach's Alpha) for RTOP and EQUIP

RTOP		EQUIP	
Category (No. of Items)	Alpha	Category (No. of Items)	Alpha
Lesson design/implementation (5)	.842	Instruction (5)	.928
Propositional knowledge (5)	.812	Discourse (5)	.933
Procedural knowledge (5)	.870	Assessment (5)	.855
Communicative interactions (5)	.883	Curriculum (4)	.814
Student/teacher relationships (5)	.871	Composites (5)	.943
Entire Instrument (25)	.962	Entire instrument (24)	.977

Exploratory Factor Analysis

Prior work with each protocol used factor analysis to study how the individual indicators loaded on various components. However, in an effort to treat the data equivalently, the exploratory factor analysis was run again for the data collected for this study for both RTOP (Table 2) and EQUIP (Table 3). Although these data may vary slightly (a few indicators may load on different components) from prior studies for each protocol, the general patterns remained the same. The RTOP indicators within a given construct tended not to load together. For EQUIP, the data largely loaded according to the constructs. The indicators comprising the Instruction construct all loaded together on one component; all the indicators from the

Table 2
Factor Analysis for RTOP Using Varimax Rotation

Construct	Item No.	Factor Analysis Component		
		1	2	3
Lesson design and implementation	1	.234	.537*	.401
	2	.638*	.425	.172
	3	.741*	.455	.075
	4	.130	.903*	.037
	5	.372	.633*	.324
Propositional knowledge	6	.152	.067	.803*
	7	.484	.338	.563*
	8	.212	.021	.844*
	9	.855*	−.018	.245
	10	.624*	.216	.244
Procedural knowledge	11	.741*	.354	.133
	12	.552*	.555*	.245
	13	.706*	.371	.363
	14	.375	.361	.613*
	15	.655*	.347	.133
Communicative interactions	16	.855*	.044	.193
	17	.493	.331	.438
	18	.869*	.075	.199
	19	.693*	.339	.408
	20	.309	.332	.647*
Student/teacher relationships	21	.546*	.414	.564*
	22	.569*	.531*	.297
	23	−.029	.395	.513*
	24	.241	.818*	.290
	25	.388	.577*	.549*

* Highly aligned with component (eigenvalue ≥ .50).

Table 3
Factor Analysis for EQUIP Using Varimax Rotation

Construct	Item No.	Factor Analysis Component		
		1	2	3
Instruction	I1	.742*	.311	.322
	I2	.736*	.280	.357
	I3	.527*	.509*	.314
	I4	.818*	.360	.109
	I5	.685*	.469	.296
Discourse	D1	.354	.819*	.314
	D2	.334	.861*	.169
	D3	.614*	.594*	.334
	D4	.474	.497*	.458
	D5	.282	.804*	.213
Assessment	A1	.055	.499	.733*
	A2	.741*	.461	.136
	A3	.580*	.474	.316
	A4	.649*	.479	.052
	A5	.400	.527*	.484
Curriculum	C1	.656*	.534*	−.090
	C2	.654*	.157	.450
	C3	.797*	.178	.287
	C4	.429	.126	.660*
Constructs	Instruction	.739*	.450	.321
	Discourse	.318	.854*	.289
	Assessment	.558*	.678*	.282
	Curriculum	.784*	.324	.269
	Lesson	.626*	.613*	.325

* Highly aligned with component (eigenvalue ≥ .50).

discourse construct loaded on a second component. Then, indicators comprising the assessment construct loaded on three different components, and four out of five curriculum indictors (including the composite) loaded on the same component.

Correlation Within and Between Instruments

The two instruments are highly correlated in numerous places. We first look at correlations found within the RTOP, then within EQUIP, and then finally between the two instruments. Note that all correlations are based on a sample size of 52 observations.

Correlation Within RTOP. All RTOP items are significantly and positively correlated to the summative lesson score. These correlations range from a low of $r = .477$, $p < .05$ to a high of $r = .851$, $p < .001$. Thus, the effect size or r^2 for these correlations ranged from .23 to .72. The two smallest correlations occurred on items 6—*lesson involved fundamental concept of the subject* and 8—*teacher had a solid grasp of subject matter content inherent in lesson*, but significance $p < .01$ was still seen in both cases. The two highest correlations were found on item 11—*students used a variety of means to represent phenomena* ($r = .850$, $p < .001$) and item 19—*student questions and comments often determined the focus and direction of classroom discourse* ($r = .851$, $p < .001$).

Correlation Within EQUIP. For EQUIP, the correlations are a bit more complex because individual items can be compared with each of the five overall constructs, including the overall lesson score. But for consistency in comparison, only the overall lesson score will be compared with the individual items. As such, all correlations were positive and ranged from a low of $r = .544$, $p < .01$ to a high of $r = .915$, $p < .001$. Thus, the effect size or r^2 for these correlations ranged from .30 to .84. The two smallest correlations were noted on items A1—*prior knowledge* ($r = .544$, $p < .01$) and C2—*learner centrality* ($r = .657$, $p < .001$). The two highest correlates with overall lesson score were D3—*questioning ecology* ($r = .915$, $p < .001$) and A4—*assessment type* ($r = .879$, $p < .001$).

Correlation Between RTOP and EQUIP Items and Instruments. To report all correlations between items of each instrument would produce an excessively large matrix, so a summary will be provided instead. Because most items were significantly correlated between RTOP and EQUIP, we begin by considering which items from RTOP were not correlated to one or more of the constructs from EQUIP. Specifically, RTOP item 8—*teacher had a solid grasp of subject matter content inherent in lesson* did not show a significant correlation ($p > .05$) when compared with each EQUIP item and construct. Further, items 6—*lesson involved fundamental concept of the subject* and 8—*teacher had a solid grasp of subject matter content inherent in lesson* were not significantly correlated ($p > .05$) with any of the individual constructs but were significantly correlated ($p < .05$) with three items (I3—*teacher role*, I4—*student role*, and I5—*knowledge acquisition*). All other RTOP items were correlated with one or more individual EQUIP items ($p < .001$) and with one or more of the EQUIP constructs ($p < .01$). When the individual EQUIP items and constructs were compared with the RTOP items, significant ($p < .001$) correlations were found for every EQUIP individual item and construct. Considering the above findings regarding the relationship of each scale's items to the other, it seems to show that EQUIP may be measuring a subset of items found on RTOP. This is not surprising because EQUIP seeks to measure the quality of inquiry-based instruction, and RTOP seeks to measure the degree of constructivist practice.

Regression Within and Between Instruments

A stepwise multiple regression analysis of RTOP showed that four items (4—*value alternative modes of problem solving*, 13—*thought-provoking lesson*, 19—*student questions determine focus/direction of class*, and 21—*active participation is encouraged*) could be used to predict the final RTOP summative score (Table 4). Specifically, 93.6% of the variance (adjusted R^2) is accounted for when using these four items as predictors for the final score. Because the individual correlations were all so high, multicollinearity becomes a major issue when all 25 items are used. The more parsimonious, four-item model provides a more succinct, targeted measure. The discussion section will address the value of keeping or trimming items for program evaluation.

A stepwise multiple regression calculation for EQUIP showed that four items (D1—*questioning level*, D3—*questioning ecology*, A2—*conceptual development*, and A3—*student reflection*) could be used to predict 88.0% of the variance (adjusted R^2) found in the final overall EQUIP score (Table 5). Similar to RTOP, the need for the additional items will be addressed in the discussion.

To see how well RTOP items can be used to predict the overall EQUIP score and vice versa, we conducted a stepwise multiple regression for each instrument. Highly predictive models were created in both cases (Tables 6 and 7), but as one would expect, the variance accounted for was less than seen when items within each instrument were used to predict the final lesson assessment score. Specifically, three items (I4—*student role*, A4—*assessment type*, and A5—*role of assessing*) can be used to predict 71.6%

Table 4
Multiple Regression Model for RTOP Items Used to Predict RTOP Summative Score

RTOP Items	*B*	*SE* of *B*	Beta
Constant	12.13	1.62	***
4—This lesson encouraged students to seek and value alternative modes of investigation or of problem solving.	3.18	.68	.19***
13—Students were actively engaged in thought-provoking activity that often involved the critical assessment of procedures.	5.07	1.04	.28***
19—Student questions and comments often determined the focus and direction of classroom discourse.	5.65	.97	.32***
21—Active participation of students was encouraged and valued.	6.64	1.08	.35***

Note. Adjusted $R^2 = .936$.
*** $p < .001$.

Table 5
Multiple Regression Model for EQUIP Items Used to Predict EQUIP Overall Total Score

EQUIP Items	*B*	*SE* of *B*	Beta
Constant	−.10	.16	NS
D1—Questioning level	.26	.07	.30***
D3—Questioning ecology	.26	.09	.30**
A2—Conceptual development	.33	.09	.26***
A3—Student reflection	.19	.08	.19*

Note. Adjusted $R^2 = .880$.
* $p < .05$. ** $p < .01$. *** $p < .001$.
NS = not significant.

Table 6
Multiple Regression Model for EQUIP Items Used to Predict RTOP Summative Score

EQUIP Items	*B*	*SE* of *B*	Beta
Constant	−12.17	5.15	*
I4—Student role	8.14	2.52	.36**
A4—Assessment type	5.88	2.55	.23*
A5—Role of assessing	10.62	2.39	.41***

Note. Adjusted $R^2 = .716$.
* $p < .05$. ** $p < .01$. *** $p < .001$.

of the variance (adjusted R^2) in the final RTOP summative score (Table 6). Likewise, four RTOP items (3—*exploration preceded formal presentation*, 5—*ideas often originating with students*, 9—*elements of abstraction were encouraged*, and *17—questions triggered divergent thinking*) can be used to predict 70.8% of the variance in the overall EQUIP score for a given lesson.

Discussion

Both RTOP and EQUIP have been shown to be highly reliable instruments, both in terms of item reliability (Table 1) and inter-rater reliability. However, inter-rater agreement scores were consistently higher for EQUIP even for the researchers that had more experience and training on RTOP. This might suggest that it is easier to become proficient in using EQUIP than RTOP. Both Cronbach's α and Cohen's κ are necessary, but not collectively sufficient, to justify that the instruments are valid and appropriate for measuring the quality of inquiry that transpires during a lesson. The RTOP instrument is designed to measure "reformed" teaching (Sawada, Piburn, Falconer et al., 2000), which involves, but is not limited to, inquiry-based teaching. So, it would make sense that RTOP is more valid if the goal is measuring the degree of constructivist practice, and EQUIP is more valid if the goal is to measure the quality of inquiry-based instruction that is occurring. EQUIP is designed to measure solely items that are directly associated with leading and facilitating inquiry-based teaching (Marshall et al., 2010). As such, several items that may be related to teacher effectiveness (e.g., classroom management issues and teacher content knowledge) are not included on EQUIP.

The exploratory factor analysis for RTOP showed that most of the items loaded on three components (Table 2). However, these loadings did not align with the constructs or categories used to organize the instrument (Piburn & Sawada, 2001). Prior work has justified not the constructs

Table 7
Multiple Regression Model for RTOP Items Used to Predict EQUIP Overall Total Score

RTOP Items	*B*	*SE* of *B*	Beta
Constant	1.05	.13	***
3—In this lesson, student exploration preceded formal presentation.	.19	.07	.29**
5—The focus and direction of the lesson was often determined by ideas originating from students.	.23	.08	.28**
9—Elements of abstraction (i.e., symbolic representations, theory building) were encouraged when it was important to do so.	.14	.06	.21*
17—The teacher's questions triggered divergent modes of thinking.	.26	.08	.31**

Note. Adjusted $R^2 = .708$.
* $p < .05$. ** $p < .01$. *** $p < .001$.

(e.g., lesson design and implementation) but, rather, the clustering of items around constructivist ideas such as pedagogical content knowledge. No confirmatory factor analysis was used to solidify these ideas into a single model, but based on the exploratory factor analysis, it seems that the items would have to be reorganized into different constructs before such a model would hold together. Regarding EQUIP, the exploratory factor analysis run for this study (Table 3) along with prior confirmatory factor analysis (Marshall et al., 2010) has confirmed that the five constructs (e.g., instruction and discourse) including a final overall construct score fit into a single coherent, valid model.

When all data are collectively analyzed (reliability, factor analyses, correlation, and multiple regression), a few patterns begin to emerge. First, it seems that even though they are important ideas, RTOP items 6—*lesson involved fundamental concept of the subject* and 8—*teacher had a solid grasp of subject matter content inherent in lesson* do not seem to fit well with the purpose of the instrument and with the measures used to analyze them. When creating EQUIP, we saw the importance of teachers being strong in the subject matter content for the topic studied (RTOP item 8), but subject matter knowledge is important for all effective teaching and not just reform-based or inquiry-based teaching. Further, the recent mandates to include state standards in every lesson often lead teachers to "cover" fundamental concepts but not always in a productive manner. Therefore, items that parallel items 6 and 8 on the RTOP were not included in the final EQUIP instrument.

When analyzing EQUIP, two items (A1—*prior knowledge* and C4—*organizing and recording information*) could have justifiably been trimmed to increase parsimony if only Cronbach's α was considered, but both these items have importance to the confirmatory factor analysis model and are well justified in inquiry-based instructional models and in constructivist literature (Bransford, et al., 2000; Bybee et al., 2006; NRC, 2000).

For both RTOP and EQUIP, a few items (three or four) can be used to predict a very large percent of the variance in the overall score for the lesson. Further, a few items (three or four) from one instrument can be used to predict the overall lesson score for the other instrument. This brings into question the importance of the other items on each instrument if three or four items can explain most all the variance related to the outcome variable (overall lesson performance). The problem seems to be for both instruments that multicollinearity becomes a major issue, because there is a substantial correlation seen between all the individual items and the overall lesson score.

Even though overlap exists in the data measured by the various indicators on EQUIP, it seems important to retain all the items because they all play a significant role in teaching, and all have been important in guiding formative improvements in teaching. Because EQUIP is used to look at teacher practice and program effectiveness at the micro and macro levels, each of the items and constructs allows teachers and professional development facilitators to target specific issues relating to instructional practice. Additionally, because EQUIP uses a descriptive rubric instead of a Likert scale, teachers and researchers are able to distinguish clearly between different levels of performance. This saves the need for researchers to create their own rubric that may no longer be a valid measure of the original instrument. When using EQUIP, the assumption is that all users will use the same rubric. Further, based on the reviewers involved in this study, EQUIP consistently

scored higher on inter-rater scoring—even for reviewers who had less experience using the instrument. This suggests that EQUIP may be easier to use and train others (researchers and teachers) to use.

For RTOP, if the final summative score is of primary importance, which seems to be the most common method to report results, then trimming the protocol to a more parsimonious model makes sense. This need to trim the protocol is further supported because discussions with teachers regarding the constructs for RTOP are not well substantiated by the exploratory factor analysis. If conversations are intended at the item level, then it may be important to retain some or all items.

Ultimately, users need to define their goal and purpose. If the goal is to specifically measure teaching practices based on constructivist theories, then RTOP provides a valid targeted instrument. If, however, the user seeks to look at transformation of teacher practice toward greater quality of inquiry-based instruction, EQUIP provides a more aligned and valid instrument. This claim is based on high inter-rater and item reliability, ease of use, exploratory and confirmatory factor analyses, and prior validity work (Marshall et al., 2010). The greatest problem that we see when working with other programs or visiting with other researchers is that instruments are often misused for the purpose they were intended. This results in poor, invalid results when looking at program effectiveness, and rightly so, because you are no longer measuring what was intended.

Implications

This comparative study has identified many similarities and differences between the RTOP and EQUIP. In the end, it seems that the utility of the instruments is just as important as what they are designed to assess. RTOP was designed to be used by researchers (Sawada, Piburn, Falconer et al., 2000), and scanning any science education research conference program, it is clear that it is still being used to assess many professional development programs relative to inquiry-based instruction. The extensive training needed and the abstract quality of the Likert scale make RTOP more difficult to use by researchers and practitioners in a formative sense. Specifically, what does it mean to a teacher to move from a 2 to a 4 for a given indicator? How does a researcher and a practitioner begin to develop an action plan for improvement when they are showing a summative score of 45—specifically when the constructs do not hold together via factor analysis?

Despite its limitations, some use RTOP to guide formative development of teachers. MacIsaac and Falconer (2002) used RTOP to assist physics teachers in using more reform-based practices. They state that any RTOP score greater than 50 indicates considerable presence of "reformed teaching" in a lesson. Gates (2008) and Ruth (2007) developed a descriptive rubric from RTOP training documents and hundreds of teacher observations in an effort to operationalize RTOP's Likert scale. This rubric has been used with middle school and high school teachers during professional development workshops to assist the teachers in changing their instruction to include more inquiry-based and student-centered practices. Be forewarned that when programs use individually designed rubrics or metrics, even if derived from the same instrument, reliability and validity must be reestablished. Further, it needs to be standardized to the instrument where comparisons will be made.

The development of EQUIP sought to further address these issues by using a descriptive rubric that has utility for both the researcher and the practitioner. Since the target for proficiency was written as a Level 3 (proficient inquiry) for every item, teachers are provided with a clear understanding of what they need to do to move from a Level 1 to Level 3 performance. The items, constructs, and overall score have interpretative value that is clear and concise. Teachers and researchers alike can explore the macro and micro issues surrounding the teaching performance. Also, because constructs are seen as the essence conveyed in a given area such as curriculum, the teacher is not penalized if a specific item was not addressed in an otherwise successful lesson. For example, to receive a 4 on many of the RTOP items, a teacher must conduct a lesson wrap-up that includes group-to-group and whole class discussions, which may not be appropriate for that day's lesson. This approach aims to keep teachers from feeling a need to perform for the observer during the lesson because he or she knows that the observer wants to see x, y, and z in the 50- or 90-minute lesson.

The reality is that effective instruction does not always fit concisely into a single period. For instance, the exploration portion of the lesson may comprise most of the period being observed. In such cases, it is important to be able to assess the merit of the exploration and not to provide a zero for things that are not appropriate for that given day. By giving zeros for indicators not observed on the RTOP, the collected summative data tend to be skewed, and the summative claim is often referenced as the benchmark for constructivist teaching and even further interpreted by some to be an indicator of the quality of inquiry-based instruction being led. In the end, if a reliable and valid measure is to be attained, one needs to make sure that

any instrument used closely aligns with the goal and purpose of the assessment or evaluation.

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Authors' Notes

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PROBLEMS section

Ted Eisenberg, *Section Editor*

This section of the Journal offers readers an opportunity to exchange interesting mathematical problems and solutions. Please send them to Ted Eisenberg, Department of Mathematics, Ben-Gurion University, Beer-Sheva, Israel or fax to: 972-86-477-648. Questions concerning proposals and/or solutions can be sent e-mail to eisenbt@013.net. Solutions to previously stated problems can be seen at http://www.ssma.org/publications.

Solutions to the problems stated in this issue should be posted before December 15, 2011

• **5170:** *Proposed by Kenneth Korbin, New York, NY*

Convex quadrilateral $DEFG$ has coordinates $D(-6, -3)$ and $E(2, 12)$. The midpoints of the diagonals are on line l. Find the area of the quadrilateral if line l intersects line FG at point $P\left(\frac{672}{33}, \frac{-9}{11}\right)$.

• **5171:** *Proposed by Kenneth Korbin, New York, NY*

A triangle has integer length sides x, $x + y$, and $x + 2y$.

Part I: Find x and y if the in-radius $r = 2011$.

Part II: Find x and y if $r = \sqrt{2011}$.

• **5172:** *Proposed by Neculai Stanciu, Buzău, Romania*

If a, b, and c are positive real numbers, then prove that

$$\frac{a(b-c)}{c(a+b)}+\frac{b(c-a)}{a(b+c)}+\frac{c(a-b)}{b(c+a)}\geq 0.$$

• **5173:** *Proposed by Pedro H. O. Pantoja, UFRN, Brazil*

Find all triples x, y, z of non-negative real numbers that satisfy the system of equations,

$$\begin{cases} x^2(2x^2+x+2)=xy(3x+3y-z) \\ y^2(2y^2+y+2)=yz(3y+3z-x) \\ z^2(2z^2+z+2)=xz(3z+3x-y) \end{cases}$$

• **5174:** *Proposed by José Luis Díaz-Barrero, Barcelona, Spain*

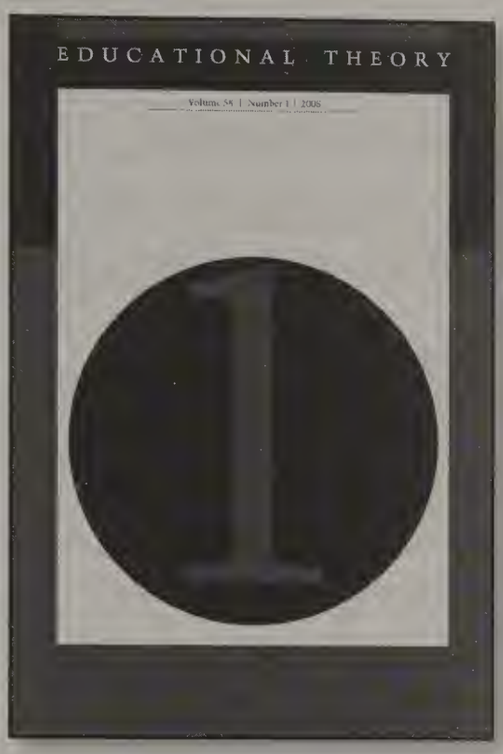
Let n be a positive integer. Compute:

$$\lim_{n\to\infty}\frac{n^2}{2^n}\sum_{k=0}^{n}\frac{k+4}{(k+1)(k+2)(k+3)}\binom{n}{k}.$$

• **5175:** *Proposed by Ovidiu Furdui, Cluj, Romania*

Find the value of

$$\lim_{n\to\infty}\frac{1}{n}\sum_{i,j=1}^{n}\frac{i+j}{i^2+j^2}.$$



EDUCATIONAL THEORY

Edited by
NICHOLAS C. BURBULES

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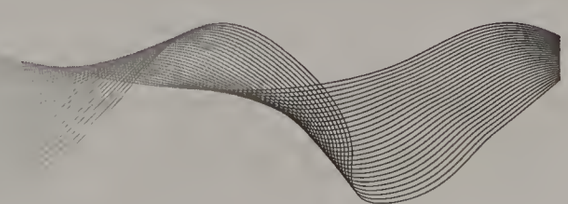

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No. of in-house reviewers: One
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Reviewers' comments are returned to the author

Manuscript topics:

Science, mathematics, and connections between science and mathematics for grades K-graduate and teacher education, especially science and mathematics articles that deal with assessment, attitudes, beliefs, curriculum, equity, research, translating research into practice, learning theory, alternative conceptions, philosophy and history of science, sociocultural issues, special populations, technology, nontraditional forms of instruction, and science/technology/society.

Manuscript guidelines/comments:

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1. An abstract not to exceed 200 words on a separate page
2. Typed double-spaced manuscript using a 12-point or larger font, with 1″ margins top, bottom, and sides. Manuscript should be limited to 25 pages for text and references. Up to 5 additional pages total will be allowed for figures, tables, and appendices.
3. To maintain anonymity, DO NOT include a cover page with author information. In the manuscript, author(s) citing their own work should cite as follows: In text: Author (2007) found… On reference list: Author (2007). *Journal Title.* (Do not include title of article or volume and page #)
4. Graphics should be black type on white background. Do not use color in graphs or figures. Follow APA guidelines for table and figure format and titles. Each table or figure should be on a separate page at the end of the manuscript, with a note within the manuscript where the graphic should be placed. Use no smaller than 8-point font for text on figures; use no smaller than 11-point font for tables. Figures and tables should be no wider than 6.75 inches.
5. A copyright form signed by all authors on the paper to be used by the journal if the paper is accepted for publication. If the paper is rejected, the journal office will shred the form. Up front submission of copyright ensures a timely publication of your manuscript.

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All manuscripts are subject to a review process. Manuscripts should not have been previously published nor be under consideration for publication in any other journal.

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The manuscript will first be evaluated for fit with the journal guidelines, alignment with APA, and topic alignment with priorities of the journal. The Editor will reject manuscripts that do not adhere to these criteria without review.

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- Relevant, timely, and significant
- Addresses K-graduate science or mathematics education issues
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- Reflect current theoretical/literature/practice-based perspectives
- Problem/Research Questions
- Theoretical framework/Literature Review
- Design/Instrumentation/Procedure
- Data Analysis/Results
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- Adds new knowledge

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LETTER FROM the editor

Dear *School Science and Mathematics* (SSM) journal readers:

I want to begin by first thanking Dr. Carla Johnson for all of her hard work and dedication to making our transition as co-editors seamless. I was honored to be selected to continue in Dr. Gerald Kulm's professional footsteps. As per *School Science and Mathematics*' mission, I vow to "promote research, scholarship, and practice that improves school science and mathematics and advances the integration of science and mathematics."

Of course, I know the importance of these disciplines and how they are naturally connected in ways which make integration important. However, I would also like to make a case for including an "A" in STEM (science, technology, engineering, and mathematics) so that it becomes STEAM. That "A" is the arts.

Research on arts learning experiences, *Critical Evidence: How the Arts Benefit Student Achievement* (2005, published by the National Assembly of the State Arts Agencies in collaboration with the Arts Education Partnership), indicates that the study of arts benefits students. Arts experiences for students contributes to:

- the development of academic skills, including the areas of reading and language development and mathematics;
- the development of certain thinking, social, and motivational skills that are considered basic for success in school, life, and work; and
- teacher innovation, a positive professional culture, community engagement, increased student attendance, effective instructional practice, and school identity.

I have participated in many discussions with preservice teachers, classroom teachers, colleagues, and friends who declare that without the arts, STEM is not creative. Exercises can be done without thinking or creativity, and that is why I believe schools sometimes tease out the creativity; students think doing mathematics is all about memorization of rules and procedures. However, when I do mathematics I use logical reasoning, patterns, and creativity to solve problems.

In an article published for the National Science Teachers Association WebNews Digest (2010), *Creativity Connecting the Arts with Science, Technology, Engineering, and Mathematics*, comments to the blog included the following:

- Combining science and the arts "lets students see how both of these have been and still are quests to examine and explain the world around us . . . Students see that curiosity, creativity, imagination and attention to detail are traits in common to artists/writers and scientists" (Inez Liftig).
- Both scientists and visual artists rely on common process skills "drawing on curiosity, asking questions, observing, seeing patterns, and constructing meaning" (Debby Chessin).

As I became more confident in my teaching at a large urban public school, I learned to create lessons that integrated mathematics with other subjects besides science. When I did this, I noticed that some students who struggled mightily with algebra and other mathematical topics seemed to shine when I used M. C. Escher and Islamic Art activities to teach geometry.

Last academic year, I contacted a professor, Regina Truhart, in the University of Cincinnati's College Conservatory of Music (CCM). I needed to create a presentation for the Cincinnati Art Museum's *Evenings for Educators* that connected mathematics with dressmaking. Regina taught courses in patterning; her students were learning to create patterns for costumes. I visited her courses and talked with the students. Many of them reported their dislike of mathematics, and yet they used measurement and mathematical processes to design and create costumes for operas and plays in CCM.

Finally, this past summer I had the privilege of attending the African Art Institute (AAI) at Northern Kentucky University with 78 art teachers from across the United States. I was definitely out of my "math-world" comfort zone for an entire week. Ghanaian artists taught us glass bead making, Kente cloth weaving, bronze lost-wax casting, Adinkra cloth stamping, and hand-building pottery. Not only did I learn these arts, I also realized the dedication that art teachers have toward using lessons which integrate mathematics and art. Art teachers at the AAI delighted in telling about these lessons.

What would our world be like without mathematics and science? Without art? I believe our students need to understand and appreciate the connections between the disciplines. We, as teachers and teacher educators, can help in this endeavor.

Thank you for your dedication to our *SSM* organization and the students who will be impacted by your efforts to endorse and conduct research, scholarship, and practice that improves school science and mathematics and advances the integration of science, mathematics, and the arts—STEAM.

Regards,

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Metaphors Reveal Preservice Elementary Teachers' Views of Mathematics and Science Teaching

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Typically, experiences shape one's attitudes toward the "thing" that is being experienced, whether it is a person, pet, movie, etc. Classroom experiences also shape one's attitudes toward a subject, teacher, learning, and so forth. Studies have shown that attitudes become more negative as students move from elementary to secondary schools. Elementary preservice teachers have had many classroom experiences by the time they reach their methods courses. These varied experiences have shaped their attitudes about the learning and teaching of mathematics and science.

Reform efforts, especially in mathematics and science support nontraditional classroom experiences. Instead of memorizing facts, mathematics and science standards (National Council of Teachers of Mathematics [NCTM], 2000 & National Research Council [NRC], 1996) emphasize the processes of learning as important. NCTM (2000) deems the processes of problem solving, communicating, reasoning and proof, making connections, and representations just as important as the content. Science (NRC, 1996) also emphasizes students' understanding through inquiry, connections, and resources/hands-on learning. Process in science and mathematics is important. Mathematics and science standards also encourage "active" learning through worthwhile tasks that are challenging and interesting to students.

Emotions, attitudes, beliefs, and values are affective variables that influence their behavior and learning (Bandura, 1986). Emotions are physiological reactions connected to personal goals and attitudes. Attitudes refer to someone liking or disliking a familiar target (Hannula, 2002). Attitudes can be described as outward, observable actions relating to beliefs (Munick, 2007). Beliefs can be defined as "one's subjective knowledge, which includes whatever knowledge one considers to be true" (Munick, 2007). Beliefs influence one's perception (Pajares, 1992). Thus, if a student believes he or she is not good at learning/teaching of a subject, then he or she will act accordingly. Therefore, beliefs play an important role in learning and teaching (Leder, Pehkonen, & Torner, 2002). Brand & Wilkins (2007) and Ruffins (2007) found from preservice teachers' writings that their prior mathematics and science experiences revealed their attitudes, anxieties, and negative feelings toward the learning and teaching of mathematics and science. One's experiences determine how attitudes affect what a person will see, hear, think, and do. Typically, people will react favorably or unfavorably to situations, people, and/or events based on their attitudes. Accordingly, teachers' actions may be shaped by their own personal attitudes (Bandura, 1986). The previous statement leads to the questions, "What are preservice teachers' dispositions toward teaching mathematics and science?" and "Are their dispositions about teaching mathematics different from their perceptions about teaching science?"

The purpose of this study was to examine preservice teachers' attitudes about teaching mathematics and science. According to research (Frykholm, 1991) teaching attitudes may predispose preservice teachers to particular behaviors and ways of teaching. Initially, the researchers thought that using preservice teachers' metaphors about ways of teaching science and mathematics might give insight into their perceptions about the teaching and learning of mathematics and science. Metaphors can provide students a comfortable way to express their true thoughts and feelings about mathematics and science. Typically, students do not state, "I hate mathematics" or "I hate science." Metaphors represent an explicit comparison and interaction among conceptual representations of content, pedagogy, students, self, and classroom actions. Students can express themselves by relating their attitudes/beliefs to a context that allows them to reveal their true attitudes in a nonthreatening manner. Using metaphors enable students to transfer learning and understanding from what is known to what is less known in a vivid manner, enhancing learning (Petrie, 1979).

Metaphors can evoke powerful imagery that helps interpret as well as convey one's thinking. They provide opportunities for people to express their thinking about (1) themselves, (2) other people, and (3) their world. Further, creating metaphors provides opportunities for capturing the essence of people's beliefs. Documentation exists throughout literature supporting the use of metaphors as a guide for understanding ideas about teaching practices (Berliner, 1990; Caine & Caine, 1997; Fleener, 2002; Marshall, 1990; Tobin, 1990). Lackoff and Johnson (1990) suggest that metaphors can condition the way we think of

ourselves and others, of events, and even nations. Metaphors subtly influence the way we think. In addition, Tobin (1990) argues that the metaphors educators knowingly or unknowingly use "guide many of the practices adopted by teachers" (p. 123). Tobin and LaMaster (1995) believe that metaphors can be used to conceptualize particular teaching roles that may guide the practices adopted by teachers. Several studies have indicated that reflection through metaphor can be a means by which preservice teachers come to terms with experiences (Sillman & Dana, 2001). Metaphors can provide an important focus for reflection in teacher education programs. Duffy, Gipe, and Richards (1992) also state, "Researchers interested in alternative ways to evaluate teachers' cognitions suggest that beginning professionals' metaphors may also indirectly reveal their beliefs and orientations about teaching" (p. 3). If prospective teachers' metaphors reveal their conceptualizations about teaching and learning, then the examination of these metaphors may provide an opportunity for students and their teachers to reflectively and critically examine those beliefs. Petrie's (1979) research found that using metaphors provides an avenue for guiding changes in students' cognitive processes. This study adopted the view that metaphors provide insight about prospective teachers' conceptualizations of the role of the teacher and the learner. The examination of these metaphors can provide opportunities for teacher educators to reflectively and critically examine their beliefs.

Sfard (1998) gleaned literature analyzing metaphors that have guided, up to this point, the theories behind teaching and learning. She identified two major categories of metaphors that inform thinking about teaching and learning. Sfard labeled the two, "acquisition" metaphors and "participation" metaphors. Acquisition metaphors portray learning as an act of obtaining knowledge. Learners must gain ownership of the knowledge from the teacher. Acquisition metaphors describe teaching/teachers delivering or giving the knowledge to be acquired. These types of metaphors also imply that there is an endpoint. Once the knowledge is gained, there is nothing else. The participation metaphors refer to learning as ways of knowing. Learning emerges from participation in activities. Here, the teacher is seen as a co-participant and preserver of discourse. Ways of knowing implies that knowledge is not stagnant or that there is not just one way of knowing.

In recent years (NCTM, 2000 & NRC, 1996), there has been a call for reform in the ways of teaching science and mathematics. The reform efforts call for students to learn mathematics and science with understanding and that all students can be expected to understand and apply mathematics and science beyond classroom walls. Students who memorize facts without understanding are not sure when or how to apply their knowledge. Learning with understanding is enhanced by classroom interactions, discussions where students explain and justify their solutions, and the development of reasoning skills. In order for students to learn mathematics and science with understanding, a shift from teacher as knowledge giver to teacher as facilitator and co-participator must take place. Problem-centered learning (Wheatley & Reynolds, 1999) and inquiry-based learning (NRC, 1996) are two types of environments that support students learning mathematics and science with understanding. In both of these environments, teachers pose tasks. The students work in collaborative pairs solving the tasks. Next, the students and teacher participate in an interactive discussion where students explain and justify their solutions.

The dichotomy of the two previous metaphor categories suggested by Sfard does not completely match the changes the reform efforts support. The two previous categories could also be thought of in terms of behaviorism and empiricism. Martinez, Sauleda, and Huber (2001) suggest basing metaphors on three dimensions of learning. Their third differentiation may be more in line with the reform efforts than the previous two metaphor categories. Their research proposes a situative or socio-historic perspective. This third view places learning in the authentic participation within a community of participants. Knowledge is thus distributed among individuals in a social community.

Method

In this study, we collected and analyzed metaphors in order to develop insights and understandings of preservice teachers' perceptions about teaching science and mathematics. We used a constant comparative method (Strauss & Corbin, 1998) to investigate and describe students' perceptions.

Participants

In the present study, we collected metaphors from 47 preservice elementary education majors. These students were university juniors and/or seniors enrolled in their science methods course and/or their second mathematics methods course. Out of the 22 participants enrolled in the science methods course, one was male. Enrolled in the mathematics methods course were two males and 23 females.

Procedures

The researchers collected metaphors during the students' mathematics or science methods course on the first day of class. The students were handed an 8 $^1/_2$ ″ × 11″

sheet of paper with the following sentence, "Teaching math/science is like _____ because _____." Directions on the paper asked the students to illustrate their metaphor on the same sheet of paper. There was plenty of room on the paper for the students to write as much as they felt necessary to explain their metaphor. The researchers did not hold discussions about metaphors nor did they give examples of metaphors prior to the participants completing the form. Participants were told in advance that the material would be used in this study. Participants signed a consent form giving permission to use their metaphors in this study. Students enrolled in these methods courses must have completed nine or 12 semester hours of content mathematics and eight to 12 semester hours of content science. The students would have experienced a variety of teaching styles in these prerequisite classes.

Both authors (instructors of the mathematics and science methods courses) analyzed the metaphors separately. After analyzing them independently, the authors met to compare and discuss the categories. Each author highlighted the descriptive words (used by the preservice teacher) that he or she felt connected the metaphor to a particular category. If there was any disagreement, then the authors looked at the illustrations in order to gain a better understanding of what the student was trying to convey. Subsequently, authors agreed on categories and placed the metaphors within those categories.

Results

Five different categories of metaphors emerged during the data analysis process. Table 1 gives the names of the categories and the number of responses matching each one to mathematics or science. Following Table 1 are explanations and examples of each type of metaphor.

Table 1
Metaphor Categories

Category	Frequency—Mathematics (%)	Frequency—Science (%)
End-product	64	32
End-product/process	8	14
Process	0	23
Overwhelming	20	18
Unclear	8	13

Category 1: End-Product

The participants' responses placed in the category "*end-product*" used descriptive words such as, complicated, challenging, outcome, solving, confusing, right ingredients, right outcome, skills, get answers, conquer, laying a foundation, and sequential. This category was the most common for the mathematics students. Sixteen mathematics students and seven science students characterized the teaching of mathematics and science as focusing on the end-product.

Sample End-Product Metaphors

1. "Teaching mathematics is like reading a novel because each chapter gives new information and the information builds to make sense, and in the end you get an outcome."
2. "Teaching math is like a giant jigsaw puzzle because there are so many different aspects, areas, formulas, and ways to get to an answer."
3. "Teaching math is like when you make brownies because there are so many ingredients and types but you have to have the right ingredients or else."
4. "Teaching math is like building a house with bricks because it takes a lot of patience and many different components to make it whole."
5. "Teaching science is like working a puzzle because it may sometimes be difficult, but the end result is worth it."
6. "Teaching science is like a challenge because teachers challenge students to learn new material every day."

These metaphors stress *the end* of the activity in order to obtain something. That end-product is predetermined. Whether it is the picture on a puzzle box, a recipe, or a house plan, these metaphors seemed to focus on the end result (something already predetermined). The puzzle, the recipe, and the house all have a "predetermined" end. Once the end-product is reached, there is nothing else to "get" or to strive for. These metaphors also do not focus much on the methods and/or processes of mathematics and science. They focus on the end.

These metaphors are similar to Sfard's (1998) acquisition metaphor category and to Martinez et al.'s (2001) behaviorism/empiricism perspective. The emphasis in this category implies the teacher as the "knowledge" authority and the learners as passive. In this situation, learning happens when an individual acquires a predetermined set of knowledge.

Category 2: End-Product/Process

Six participants' metaphors were placed in the category, end-product/process. Two participants were in the mathematics methods course, and three were in the science methods course. These contained descriptive phrases such

as *long, hard journey*, *difficult until you reach the top*, and *do not know until something is discovered*. Each metaphor implied mathematics and science is something unknown and hard to reach.

Sample End-Product/Process Metaphors

1. "Teaching math is like running cross-country track because each step is different from the last and each terrain is different. It is a long, hard journey, but when you get to the finish line, the sense of accomplishment is overwhelming."
2. "Teaching math is like climbing a mountain because the journey is difficult but, when the child reaches the 'top', the feeling is astonishing."
3. "Teaching science is like a jungle because you don't know what you will find until you explore and discover."

The metaphors in this category mention the process. The process is not discussed in detail. These metaphors also mention the end, the finish line, or the top, indicating that the end is predetermined and that there is little to nothing after the "end result." Even the "jungle" description is indicative of an end—you do not know until you discover. This implies one could wander with or without making a discovery. It also implies that you will know once the discovery is made, then that is all, there is no more to be discovered.

This category is similar to the participation metaphor and what Martinez et al. (2001) label as the constructivist or cognitive point of view perspective. Learning is seen as a process, not a static predetermined amount of knowledge to be acquired. The learner chooses his/her route. The teacher adjusts with the learners as co-participant.

Category 3: Process

The five participants' responses in this category were students enrolled in the science methods course. Some examples of their descriptive words are interaction, change, discover, exploring, and interesting.

Sample Process Metaphors

1. "Teaching science is like watching a flower grow because it is fascinating to observe the stages of life and the interactions of soil, nutrients, water, sun, and wind. The growing knowledge of the children can be likened to the beautiful growing flower."
2. "Teaching science is like discovering a new world because you are always finding something new."

These metaphors discuss something happening and do not focus on the "end result." These metaphors contain action words implying that the teacher will not necessarily know every detail along the way but is involved in the process with the learners.

This category is similar to the third category mentioned in Martinez et al. (2001) situated or socio-historic perspective. Both metaphors relate to a system, a community where learning emerges from authentic participation in the activities of the community. Here, the teacher and students are actively participating in real world events, e.g., "stages of life and interactions of soil, wind, water, and sun" and "a new world." In both metaphors, there is not an end to be obtained.

The authors found some of the students' metaphors did not fit in any of the three categories above. The last two categories are labeled "overwhelming" and "unclear."

Category 4: Overwhelming

Nine responses, five math and four science, were placed into this category labeled as negative. The students described teaching of mathematics/science as dark, intimidating, does not make sense, a lot of work, no understanding, and scary.

Sample Overwhelming Metaphors

1. "Teaching math is like teaching another language because students may not understand a single word."
2. "Teaching math is like riding a merry-go-round of confusion because the students do NOT always understand and you go around the same point over and over."
3. "Teaching math is like being stranded in the ocean because I always start to sink without help."
4. "Teaching science is like a forest because it's dark and scary—and no one truly understands it."
5. "Teaching science is like math because they both seem intimidating."

All of these metaphors used the *overwhelming* part of something that could have been fun or positive; instead, they chose the negative aspect. For example, some people enjoy a merry-go-round and think that riding it is fun. Instead, the student focused on the mundane part of the ride equating teaching mathematics as doing the same thing over and over. An example for teaching science was equated with a dark and scary forest, instead of seeing the exciting possibilities of finding many different plants, animals, etc. This implies you will not know what is ahead.

Category 5: Unclear

Five participants' responses were categorized as *unknown*. These students did not talk about a process, an end product, or interaction in a social setting.

1. "Teaching math is like riding a roller coaster because it is fun."
2. "Teaching math is like a light bulb just before it pops and goes out because there will be a point that I won't know what my kids know."

3. "Teaching science is like sunshine because it touches everything."

4. "Teaching science is like a spider web because everything connects in some way."

These metaphors did not portray a clear picture of what the students were thinking. Even the illustration that they drew to help describe their metaphor did not give insight into their thinking. The two science metaphors seem to imply that the students have heard or know that science is involved in everything but do not understand how.

Discussion

The majority of the mathematics metaphors fell into the end-product category, whereas the science metaphors were distributed evenly across categories. The two categories, end-product/process and process, included more science metaphors than mathematics. This may be because students think of science in terms of exploration, either through teacher demonstration or through their own explorations. In previous science classrooms, students may have been allowed to "discover" but typically not in mathematics classrooms. In addition, the media often discusses new science "discoveries" giving the impression that something new is to be learned, maybe there is not one right answer, and/or science changes. Whereas in mathematics, the focus is typically on the "right answer," and there is not a time to "explore." Therefore, the students think the focus of mathematics is an end-product answer.

The metaphors for this study also fall in line with the research conducted by Martinez et al. (2001). In their research of classroom teachers' metaphors, 57% fell into the behaviorist category, 38% fell into the constructivist category, and only 5% fell into the situative/socio-historic perspective. From this research, it is not surprising that the majority of the preservice teachers' metaphors also fell within a behaviorist category. As long as classroom teachers believe that the learner must gain knowledge from the teacher, how can learners experience active learning? Thus a cycle continues, students grow up in "behaviorist" classrooms, enter college believing that teachers are the givers of knowledge, and then become teachers who believe students must receive the knowledge that they give to them.

These metaphors collected from the preservice teachers seem to suggest that students' previous experiences and beliefs continue to deem the end-product as important. Ultimately, we would like students to understand the importance of the processes (as set forth in NCTM and NRC) involved in understanding mathematics and science concepts. As methods instructors, we originally set out to only analyze preservice teachers' attitudes. After analyzing the metaphors, the researchers found it important to "look" at their own classroom environments, content, and methodology for opportunities to provoke the preservice teachers to view mathematics and science in terms of process, as well as product. We plan to provide experiences with inquiry-based science and problem-centered mathematics to help our own students see beyond the "answer" or end product of instruction. In addition to actions within our own methods courses, we plan to establish a partnership with a local fifth grade classroom and incorporate practicum hours into the two methods courses. During the practicum hours, the preservice students and instructors have opportunities to engage in worthwhile science and mathematics activities with fifth graders. The college students have opportunities to "see" mathematics and science in action as well as experience teaching mathematics and science in an inquiry fashion.

If the processes of learning mathematics and science are important, then what do the metaphors imply? From research (Richardson, 1996; Ruffins, 2007), we have seen that teachers' practice is ultimately influenced by beliefs about teaching and their personal knowledge of the subject matter. These beliefs influence teachers' actions and decisions they make in the classroom. Also from research (NCTM, 2000), we know that students learn through the experiences and opportunities provided by teachers. It seems, from the metaphors, that the focus of mathematics and science classes has tended to be on the answer and not on the processes. If preservice teachers are to think about the process of learning being as important as the end product, as well as aligning their beliefs with the reform efforts, then they need to experience worthwhile activities that promote learning with understanding in a community through inquiry and problem solving. In addition to understanding the preservice teachers' perspectives of teaching mathematics and science, this research may lead to insights into how educators can structure methods courses to challenge dispositions about content knowledge.

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Linking Preservice Teachers' Mathematics Self-Efficacy and Mathematics Teaching Efficacy to Their Mathematical Performance

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This study examined preservice teachers' mathematics self-efficacy and mathematics teaching efficacy and compared them to their mathematical performance. Participants included 89 early childhood preservice teachers at a Midwestern university. Instruments included the Mathematics Self-Efficacy Scale (MSES), Mathematics Teaching Efficacy Beliefs Instrument (MTEBI), and the Illinois Certification Testing System (ICTS) Basic Skills Test. The results indicate that preservice teachers' mathematics self-efficacy is positively correlated to their personal mathematics teaching efficacy. In addition, their mathematical performance is related to their mathematics self-efficacy and mathematics teaching efficacy. In regard to affecting student outcomes, only those preservice teachers who are very confident in their ability to teach believe they can have an effect on their students. Implications on teacher education programs are discussed.

Mathematics has long been a subject that causes fear and anxiety in students. Preservice teachers are no exception. One possible explanation is that students possess low self-efficacy in the area of mathematics. Social learning theorists define perceived self-efficacy as a sense of confidence regarding the performance of specific tasks. Bandura (1986, p. 391) defined the construct of self-efficacy as "people's judgments of their capabilities to organize and execute courses of action required to attain designated types of performances. It is concerned not with the skills one has but with the judgments of what one can do with whatever skills one possesses." In other words, regardless of mathematical ability, students' effort may be affected by their own judgment of their capability to solve mathematics problems. Mathematics self-efficacy refers to one's beliefs in their ability to do mathematics and is often assessed in terms of one's own judgment of their capabilities to solve specific mathematics problems, to perform mathematics-related tasks, and to succeed in mathematics-related courses (Betz & Hackett, 1983).

As Bandura (1993) pointed out, self-efficacy is a key factor in human competence. Self-efficacy mediates between beliefs and behaviors. Students with a high sense of self-efficacy exhibit strong achievement, whereas students with a low sense of self-efficacy exhibit the opposite (Schunk, 1981; Skaalvik & Skaalvik, 2006). When students perceive high self-efficacy, they tend to try harder and persevere longer to accomplish the task (Pajares, 2003). According to self-efficacy theories, self-efficacy beliefs are determinants of people's behavior. When students develop beliefs about their capability, they tend to determine what they do with the knowledge and skills that they have. Research examining college students' mathematics self-efficacy indicates that college students who were enrolled in higher-level mathematics (e.g., calculus) had higher mathematics self-efficacy than college students who were enrolled in lower-level mathematics courses (Hall & Ponton, 2005). Hackett and Betz (1989) found that mathematics self-efficacy and mathematical performance were correlated with each other as well as with choosing a mathematics-related major. Students who do well in mathematics feel good about their ability to do mathematics and therefore are more likely to choose a major that requires the use of mathematics.

Mathematics self-efficacy has also been found to be negatively correlated with mathematics anxiety in college students (Cooper & Robinson, 1991; Hackett & Betz, 1989). Students who feel they are good at mathematics are less likely to express fear of mathematics. Unfortunately, research has found that preservice teachers report high levels of mathematics anxiety (Bursal & Paznokas, 2006; Gresham, 2007; Vinson, 2001). In fact, they express higher levels than other undergraduate majors (Harper & Daane, 1998). This anxiety toward mathematics is higher than anxiety toward other subjects such as science (Cady & Rearden, 2007). When preservice teachers are asked to express their views of mathematics, they are likely to indicate negative views such as "Mathematics is my enemy" and "Math is something I hate" (Cady & Rearden, 2007). These fears and negative views can result from prior negative experiences with formal instruction (e.g., Brady & Bowd, 2005; Harper & Daane, 1998) and/or a lack of procedural and conceptual knowledge of mathematics (e.g., Vinson, 2001). Since research indicates that

preservice teachers demonstrate high mathematics anxiety and lack procedural and conceptual mathematical knowledge, it is a safe assumption that these preservice teachers would have low mathematics self-efficacy.

Preservice teachers' mathematics anxiety has also been found to be negatively correlated with their mathematics teaching efficacy (Bursal & Paznokas, 2006; Gresham, 2008; Swars, Daane, & Giesen, 2006). Mathematics teaching efficacy refers to one's beliefs in their ability to teach mathematics effectively (Enochs, Smith, & Huinker, 2000). Enochs et al. (2000) developed the Mathematics Teaching Efficacy Belief Instrument (MTEBI) as a modification of the Science Teaching Efficacy Belief instrument (STEBI-B: Riggs & Enochs, 1990) and found it to be a valid and reliable measurement of mathematics teaching efficacy. Bursal and Paznokas (2006) found that half of the 65 preservice teachers, in their study, who were enrolled in a mathematics methods course, felt that they would not be able to teach mathematics effectively. Students who identified themselves as having high mathematics anxiety were less confident in their abilities to teach mathematics than those students who identified themselves as having low or moderate mathematics anxiety. Gresham (2008) conducted interviews with 20 elementary preservice teachers and found that participants' responses showed that their mathematics anxiety served as a basis for their teaching efficacy beliefs. Other studies have found that methods courses and student teaching significantly increases preservice teachers' mathematics teaching efficacy (Swars, Hart, Smith, Smith, & Tolar, 2007; Utley, Moseley, & Bryant, 2005).

Although there have been numerous studies examining preservice teachers' mathematics anxiety and mathematics teaching efficacy, these studies fail to assess preservice teachers' mathematics self-efficacy as well as their actual mathematical performance. Most studies focus on elementary preservice teachers, but a recent report questioned the preparation of early childhood teachers in teaching mathematics (Ginsburg, Lee, & Boyd, 2008). There is also evidence that early childhood teachers have less content knowledge and less positive attitudes toward mathematics compared to upper clemcntary teachers (Wilkins, 2008). Therefore, it is imperative that early childhood teachers' mathematics teaching efficacy be examined. For the purposes of this study, we arc using Betz and Hackett's (1993) definition of mathematics self-efficacy as one's beliefs in their ability to do mathematics. Further, we are defining mathematics teaching efficacy as one's beliefs in their ability to teach mathematics effectively (Enochs et al., 2000). Lastly, we have defined mathematical performance as determined by the scores on the mathematics section of the Illinois Certification Testing System (ICTS) Basic Skills Test. This test is required for entrance into all certified teacher education programs in Illinois. In regard to mathematics, this test assesses the candidate's ability in six areas, including numbers and operations, measurement, geometry, probability and statistics, algebra, and mathematical reasoning, problem solving, and communication skills. The significance of this study is its examination of early childhood preservice teachers' mathematics self-efficacy and mathematics teaching efficacy as compared to their mathematical performance. The following research questions were addressed:

1. How is early childhood preservice teachers' mathematics self-efficacy related to their mathematics teaching efficacy?
2. How are early childhood preservice teachers' mathematics self-efficacy and mathematics teaching efficacy related to actual mathematical performance?
3. How do preservice teachers who rank high in their mathematical performance, mathematics self-efficacy, and mathematics teaching-efficacy differ from preservice teachers who rank low in these areas?

Methodology

Participants

The participants for this study were 89 early childhood preservice teachers from a large teacher preparation institution in the Midwest. This institution began as a school of education and has a long history of teacher preparation, preparing the majority of teachers in the state and a high percentage of practicing teachers nationwide. Early childhood teachers at this institution are certified to teach pre-K to third grade.

All participants were female. In regard to racial identity, 81 of the participants were White, five were Black/Non-Hispanic, two were Hispanic, and one reported herself as other. Forty-eight percent of the participants were juniors, and 52% were seniors. Participants at the time of this study werc in the first or second semester of their junior year or thc first semester of their senior year, just prior to student teaching. Participants were recruited in the same semester through an carly childhood issues and practices course, a mathematics methods course, and a social studies methods course.

Procedures

The researchers began this study by securing Institutional Review Board approval for research with human subjects. Since some of the possible study participants

were recruited in courses currently taught by the researchers, a graduate assistant recruited, secured consent, and administered the two instruments described. To avoid bias, the researchers were not present for this process and did not gain access to the data until the completion of the semester. All students present at the time of recruitment consented, removing any issues of bias concerning those who consented and those who did not.

Instruments

The Mathematics Self-Efficacy Scale (MSES), developed by Betz and Hackett (1993) was used to determine students' mathematics self-efficacy. The scale consists of 34 questions using a 10-point Likert-scale and includes two subscales: Mathematics Task Self-Efficacy (MTSE) and Mathematics-Related School Subjects Self-Efficacy (MRSE). The MTSE subscale asks participants to rate their capabilities to solve specific mathematics problems and perform mathematics-related tasks. Examples of questions from the MTSE subscale include: "How much confidence do you have that you could successfully add two large numbers (e.g., 5379 + 62543) in your head?" and "How much confidence do you have that you could successfully figure out how long it will take to travel from Columbus to Chicago driving at 55mph?" The MRSE subscale asks participants to rate their ability to succeed in various mathematics-related courses (e.g., basic college math, economics, and statistics). Betz and Hackett (1993) showed the instrument to be a reliable and valid measure for examining mathematics self-efficacy.

The MTEBI (Enochs et al., 2000) consists of 21 items on a 5-point Likert-scale and includes two subscales: Personal Mathematics Teaching Efficacy (PMTE) and Mathematics Teaching Outcome Expectancy (MTOE). The PMTE subscale includes 13 questions with possible total scores ranging from 13 to 65, and the MTOE subscale includes eight questions with total scores ranging from 8 to 40. Examples of questions on the MTEBI include: "I will continually find better ways to teach mathematics" and "I understand mathematics concepts well enough to be effective in teaching mathematics." The instrument has been reported to be both a both valid and reliable measure of PMTE and MTOE (Enochs et al., 2000).

The mathematics section of the ICTS Basic Skills Test was used as a measure of participants' mathematical performance (this test will be referred to as the Basic Skills Test in the remainder of the article). The Basic Skills Test assesses preservice teachers' ability in reading comprehension, language arts, writing, and mathematics. Only the score on the mathematics section was used in this study. The mathematics section of the Basic Skills Test assesses students' ability to solve problems involving integers, fractions, and decimals, unit of measurement, algebra, and geometry. Students are required to apply mathematical reasoning skills to analyze patterns. The scores for the mathematics section were obtained through the college's teacher education counseling center after obtaining permission from the participants. The scores are reported on a scale from 100 to 300.

Data Analysis

The analysis of the data included calculating Pearson product-moment correlation coefficients and conducting independent *t*-tests. Pearson product-moment correlations were used to determine the relation among the demographic variables, mathematics self-efficacy, mathematics teaching efficacy, and mathematical performance. Independent *t*-tests were used to compare the high and low groups in mathematics self-efficacy, mathematics teaching efficacy, and mathematical performance and effect sizes (Cohen's *d*) were calculated for each comparison.

Results

The results from this study are interesting and complex with thought-provoking implications for early childhood teacher preparation. To best address the research questions, the findings, and analyses are organized below by the research questions which guided this study. There were no significant correlations found between the demographic items and any of the self-efficacy scales used or the Basic Skills Test mathematics scores. Since the two subscales of the MSES were strongly correlated with each other and the full-scale score, only the full-scale score is used in further analyses and discussion.

The means and standard deviations for each of the instruments were calculated (see Table 1). Pearson product-moment correlation coefficients for the two MSES subscales, the total MSES scale, the two MTEBI subscales (PMTE and MTOE), and the Basic Skills Test mathematics score were also computed (see Table 2). These findings are described below and inform research questions 1 and 2.

Research Question 1: How is early childhood preservice teachers' mathematics self-efficacy related to their mathematics teaching efficacy?

Scores on the MSES total scale ranged from 3.68 to 9.62 on a 10-point Likert scale, showing a rather large range of mathematics self-efficacy among the preservice teachers in this study. However, the mean score of 6.51 ($SD = 1.35$) suggests that overall, these preservice teachers are generally confident in their mathematics ability. Scores on the PMTE ranged from 29 to 65 with a mean of 49.56 ($SD =$

6.28). The highest possible score on the PMTE is 65, so a mean of 49.56 suggests that overall, these preservice teachers are confident in their ability to teach mathematics. According to the Pearson product-moment correlation coefficients computed, preservice teachers' mathematics self-efficacy is related to their teaching mathematics self-efficacy ($r = .61, p < .01$). So preservice teachers who feel confident about their ability to solve mathematic tasks and do well in mathematics courses are more likely to feel confident in their ability to teach mathematics to children. The MTOE subscale of the METBI showed no correlation to preservice teachers' mathematics self-efficacy.

Research Question 2: How are early childhood preservice teachers' mathematics self-efficacy and mathematics teaching efficacy related to actual mathematical performance?

Table 1
Means and Standard Deviations of Self-Efficacy Scales and Basic Skills Test

Variable	M	*SD*
1. Mathematics tasks self-efficacy	7.00	1.26
2. Mathematics course self-efficacy	5.97	1.70
3. Full-scale mathematics self-efficacy	6.51	1.35
4. Personal mathematics teaching efficacy	49.56	6.28
5. Mathematics teaching outcome expectancy	28.26	3.57
6. Basic skills test mathematics score	257.44	24.33

The Basic Skills Test mathematics scores ranged from 193 to 300 (300 is the maximum score on the test) with a mean score of 257.44 ($SD = 24.33$). This relatively high mean suggests that at least based on this test, the preservice teachers in our study have a rather strong background in mathematics. The Basic Skills Test mathematics score was positively correlated with overall mathematics self-efficacy, MSES, ($r = .38, p < .01$) and personal mathematics teaching efficacy, PMTE, ($r = .21, p < .05$). Preservice teachers who had higher Basic Skills Test mathematics scores were more likely to be confident in their mathematics self-efficacy and high personal mathematics teaching efficacy. However, there was no correlation between the Basic Skills Test mathematics scores and MTOE.

Research Question 3: How do preservice teachers who rank high in their mathematical performance, mathematics self-efficacy, and mathematics teaching-efficacy differ from preservice teachers who rank low in these areas?

After identifying the relations among preservice teachers' mathematics self-efficacy, mathematics teaching efficacy, and the Basic Skills Test mathematics scores, the data were re-examined in order to compare preservice teachers who scored high on these various measures with those who scored low. These groups were derived by splitting the preservice teachers' scores for each measure into three groups (high, middle, low). Each group consisted of approximately a third of the participants but varied depending on the measure. Independent *t*-tests were conducted to compare the high and low groups for each measure.

Basic Skills Test Mathematics Scores

The 25 preservice teachers who scored from 193–246 on the mathematics test and 27 preservice teachers who scored from 273–300 on the mathematics test formed the

Table 2
Pearson Product-Moment Correlation Coefficients Between Self-Efficacy Scales and Mathematical Performance

Variable	1	2	3	4	5	6
1. Mathematics tasks self-efficacy	—					
2. Mathematics course self-efficacy	.68*	—				
3. Full-scale mathematics self-efficacy	.90**	.93**	—			
4. Personal mathematics teaching efficacy	.64**	.50**	.61**	—		
5. Mathematics teaching outcome expectancy	.09	.15	.13	.11	—	
6. Basic skills test mathematics score	.37**	.34**	.38**	.21*	.13	—

*$p < .05$; **$p < .01$

Table 3
t-Tests of High and Low Basic Skills Test Mathematics Score Groups

Group	M	*SD*	*n*	*t (df)*	*p*	*d*
Mathematics self-efficacy						
Low-scoring group	5.78	1.27	25	3.58 (50)	<.001*	1.00
High-scoring group	7.07	1.31	27	—	—	
Personal mathematics teaching efficacy						
Low-scoring group	48.48	6.93	25	1.54 (50)	.13	n/a
High-scoring group	51.30	6.28	27	—	—	
Mathematics teaching outcome expectancy						
Low-scoring group	27.80	4.09	25	0.57 (50)	.57	n/a
High-scoring group	28.37	3.09	27	—	—	

low and high groups, respectively. Independent *t*-tests were conducted to determine if there was a significant difference between the two groups in regard to their mathematics self-efficacy and mathematics teaching efficacy (see Table 3). The mean mathematics self-efficacy score for the low Basic Skills Test mathematics score group was 5.78 ($SD = 1.27$), whereas the mean for the high Basic Skills Test mathematics score group was 7.07 ($SD = 1.31$). The results of the *t*-test ($t = 3.58, p < .001; d = 1.00$) suggest a significant difference between the two groups in regard to their mathematics self-efficacy. The effect size indicates large differences between the two groups. Students who scored higher on the Basic Skills Test mathematics section exhibit higher mathematics self-efficacy than those who scored lower on the Basic Skills Test mathematics section. However, in comparing the two groups' personal mathematics teaching efficacy and teaching outcome expectancy, no significant differences were found when conducting independent *t*-tests ($t = 1.54, p = .13$; $t = .57, p = .57$).

Mathematics Self-Efficacy Scores

The 28 preservice teachers who scored lower than 5.85 on the MSES and 29 who scored more than 7.30 out of 10.00 formed the low and high groups, respectively. The two groups do not necessarily include the same preservice teachers as the low and high Basic Skills Test mathematics score groups that were already discussed. An independent *t*-test was conducted to determine if there was a significant difference between the low and high mathematics self-efficacy groups in regard to their Basic Skill Test mathematics score (see Table 4). The mean of the Basic Skills Test mathematics scores for the low mathematics self-efficacy group was 250.89 ($SD = 23.42$), and the mean for the high mathematics self-efficacy group was 268.89 ($SD = 22.41$). The results of the *t*-test ($t = 2.94, p < .01; d = .79$) suggest a significant difference between the two groups in regard to their Basic Skills Test mathematics scores. Again, the effect size indicates large differences between the two groups. Preservice teachers who felt good about their mathematics abilities were more likely to have higher scores on the Basic Skills Test mathematics section than students who did not feel good about their mathematics abilities.

An independent *t*-test was also conducted to determine if there was a significant difference between the low and high mathematics self-efficacy groups in regard to their mathematics teaching efficacy. The mean mathematics teaching efficacy score for the low mathematics self-efficacy group was 44.68 ($SD = 5.06$), and the mean for the high mathematics self-efficacy group was 54.48 ($SD = 5.48$). The results of the *t*-test ($t = 7.01, p < .001; d = 1.86$) suggest a significant difference between the two groups in regard to their mathematics teaching efficacy. The effect size indicates very large differences between the two groups. Preservice teachers who felt good about their mathematics abilities were more likely to also feel good about their ability to teach mathematics than preservice teachers who did not feel good about their mathematics abilities. In comparing the two groups' mathematics teaching outcome expectancy, no significant differences were found when conducting independent *t*-tests ($t = 1.34, p = .19$).

Personal Mathematics Teaching Efficacy Scores

The 27 preservice teachers who scored lower than 47 and 28 who scored more than 52 on the PMTE scale formed the low and high groups, respectively. Again, the

Table 4
t-Tests of High and Low Mathematics Self-Efficacy Groups

Group	M	*SD*	*n*	*t (df)*	*p*	*d*
Basic skills mathematics score						
Low-scoring group	250.89	23.42	28	2.94 (54)	<.01*	.79
High-scoring group	268.89	22.41	29	—	—	
Personal mathematics teaching efficacy						
Low-scoring group	44.68	5.06	28	7.01 (55)	<.001*	1.86
High-scoring group	54.48	5.48	29	—	—	
Mathematics teaching outcome expectancy						
Low-scoring group	28.07	2.96	28	1.34 (55)	.19	n/a
High-scoring group	29.31	3.92	29	—	—	

Table 5
t-Tests of High and Low Personal Mathematics Teaching Efficacy Groups

Group	M	*SD*	*n*	*t (df)*	*p*	*d*
Basic skills mathematics score						
Low-scoring group	251.15	23.93	27	2.62 (52)	<.05*	.71
High-scoring group	267.70	22.49	28	—	—	
Mathematics self-efficacy						
Low-scoring group	5.34	1.28	27	6.92 (53)	<.001*	1.87
High-scoring group	7.43	0.95	28	—	—	
Mathematics teaching outcome expectancy						
Low-scoring group	27.74	2.58	27	2.24 (53)	<.05*	.61
High-scoring group	29.57	3.40	28	—	—	

students in these high and low groups are not necessarily the same students in the high and low Basic Skills Test mathematics score groups or in the high and low mathematics self-efficacy groups that are described above. Independent *t*-tests were conducted to determine if there was a significant difference between the low and high personal mathematics teaching efficacy groups in regard to their Basic Skill Test mathematics scores, mathematics self-efficacy, and MTOE (see Table 5). The mean Basic Skills Test mathematics score for the low mathematics teaching efficacy group was 251.15 ($SD = 23.93$), and the mean for the high mathematics self-efficacy group was 267.70 ($SD = 22.49$). The results of the *t*-test ($t = 2.62$, $p < .05$; $d = .71$) suggest a significant difference between the two groups in regard to their Basic Skill Test mathematics scores. The medium effect size indicates some differences between the two groups. The mean mathematics self-efficacy score for the low personal mathematics teaching efficacy group was 5.34 ($SD = 1.28$), and the mean for the high personal mathematics teaching efficacy group was 7.43 ($SD = .95$). The results of the *t*-test ($t = 6.92$, $p < .001$; $d = 1.87$) suggest a significant difference between the two groups in regard to their mathematics self-efficacy. Again, the effect size indicates very large differences between the two groups.

The mean MTOE score for the low mathematics teaching efficacy group was 27.74 ($SD = 2.58$), and the mean for the high mathematics teaching efficacy group was 29.57

($SD = 3.40$). The results of the t-test ($t = 2.24$, $p < .05$; $d = .61$) suggest a significant difference between the two groups in regard to their MTOE scores. The medium effect size indicates some differences between the two groups. Preservice teachers who were more confident in their teaching abilities were more likely to be confident in their mathematics abilities, have higher mathematic scores, and believe they could affect their students more than those preservice teachers who were not confident in their teaching abilities.

Discussion

Research question one asked how early childhood preservice teachers' mathematics self-efficacy is related to their mathematics teaching efficacy. Previous studies have focused on mathematics anxiety in relation to mathematics teaching efficacy and have found negative correlations between the two (Bursal & Paznokas, 2006; Gresham, 2008; Swars et al., 2006); however, to our knowledge, no studies have examined the relation between mathematics self-efficacy and mathematics teaching efficacy. As described in the results section, preservice teachers who reported higher mathematics self-efficacy were more likely to feel confident in their ability to teach mathematics but did not feel more confident in their ability to affect student outcomes either positively or negatively. So having confidence in mathematics abilities influences mathematics teaching efficacy, but it does not influence beliefs regarding the effect one may have on students. Preservice teachers with high mathematics self-efficacy know they can teach mathematics, but they do not know if it will be effective for their students. One possible explanation for this finding is preservice teachers' lack of experience working with students. They essentially lack the experience that would help them know what they can do to affect students' understandings. As previous studies (Swars et al., 2007; Utley, Moseley, & Bryant, 2005) have found, methods courses and student teaching experiences can improve mathematics teaching efficacy, which has been found to be related to student achievement (Swars et al., 2006). Perhaps these experiences should also be used to show students directly how they can affect students' understandings.

Research question 2 addresses how early childhood preservice teachers' mathematics self-efficacy and mathematics teaching efficacy are related to actual mathematical performance. The findings of this study support Hackett and Betz's (1989) findings that mathematics self-efficacy is positively correlated to mathematics performance. Preservice teachers scoring higher on the Basic Skills Test mathematics section were significantly more likely to report being self-efficacious in regard to their mathematics ability and their ability to teach mathematics. It would be expected that those who have a higher content knowledge of mathematics would feel more confident about their mathematics abilities; however, having higher mathematical content knowledge is only one part of teaching mathematics, so the finding that mathematics teaching efficacy is related to mathematical performance was interesting and is an important contribution of this study. Preservice teachers seem to think if they have content knowledge, they can teach the topic. But again, even though they have the content knowledge and believe they can teach it, they are still unsure about their ability to influence students' learning.

Lastly, research question 3 looked at how preservice teachers who rank high in their mathematical performance, mathematics self-efficacy, and mathematics teaching efficacy differ from preservice teachers who rank low in these areas. This question was informed by the comparing of the high and low groups for the three different measures and provided some interesting findings. Preservice teachers who scored high on the Basic Skills Test mathematics section rated their mathematics self-efficacy higher than those preservice teachers who scored low on the Basic Skills Test mathematics section. This finding can be equated with Hall and Ponton's (2005) study in which they found differences in mathematics self-efficacy between college students enrolled in lower- and higher-level mathematics courses; however, Hall and Ponton did not collect direct mathematical performance data. When comparing the two groups on their mathematics teaching efficacy and teaching outcome expectancy, no significant differences were found. Preservice teachers who scored low on the Basic Skills Test mathematics section felt just as confident in their abilities to teach and affect student outcomes as those preservice teachers who scored high. This lack of difference between the two groups seems to imply that having higher scores, in regard to mathematical performance, does not affect confidence in teaching mathematics or influencing students' learning. Again, the lack of teaching experience may be the best explanation. Perhaps those who scored lower do not realize the importance of their ability to perform mathematically in being able to teach mathematics.

Preservice teachers who rated their mathematics self-efficacy as high scored significantly higher on the Basic Skills Test mathematics section than those preservice teachers who rated their mathematics self-efficacy as low. This finding further supports the positive relation between

mathematics self-efficacy and mathematical performance as found by others (Hackett & Betz, 1989; Hall & Ponton, 2005). The high mathematics self-efficacy group also rated their mathematics teaching efficacy significantly higher than the low mathematics self-efficacy group. Therefore, although there was no difference in teaching self-efficacy based on the Basic Skills Test mathematics scores of the high and low score group, preservice teachers' mathematics self-efficacy does seem to have some influence on their mathematics teaching efficacy.

In regard to mathematics teaching efficacy, the group of preservice teachers that rated themselves higher had significantly higher Basic Skills Test mathematics scores and rated their mathematics self-efficacy significantly higher than those preservice teachers who rated themselves lower on their mathematics teaching efficacy. This finding is a significant one because limited research exists in which mathematics teaching efficacy and mathematical performance is examined. In a related study, Swars (2005) found that preservice teachers' mathematics self-efficacy was related to past experiences with mathematics, but the study utilized interviews regarding mathematics experience rather than actual mathematics score data. Swars' study did not exam mathematics self-efficacy. The finding from the current study implies that if one is confident in his or her ability to teach mathematics, then they are more confident in their ability to do mathematics and are more likely to perform better on a test of mathematical performance. It is important to note that in comparing these two groups, there was a significant difference between them in regard to the effect they would have on student outcomes. Preservice teachers who are confident in their ability to teach believe they can have an effect on their students. It is possible that this group of students may have more experience in the classroom than the group who rated themselves low on mathematics teaching efficacy. One other possible explanation is the low level of mathematics anxiety that these preservice teachers may have. Previous studies (Bursal & Paznokas, 2006; Swars et al., 2006) have found negative correlations between mathematics anxiety and mathematics teaching efficacy. Since mathematics scores and mathematics efficacy do not seem to clearly explain this finding, it would be helpful to further explore mathematics anxiety and teaching outcome expectancy.

It should be remembered that all of the comparisons yielded medium to very large effect sizes. The effect sizes indicate a practical difference between the high and low groups in each comparison. As teacher educators, we must be aware that a difference exists between those students who have a high mathematics self-efficacy and low mathematics self-efficacy as well as those who have a high mathematics teaching efficacy and low mathematics teaching efficacy. We should consider their needs and abilities in designing their coursework and other experiences.

Implications

These findings provide interesting implications for both current preservice early childhood teachers' preparation and for future research directions. Teacher preparation programs must examine their general education mathematics expectations along with their mathematics pedagogy courses to identify opportunities to modify curricular expectations that allow preservice teachers' hands-on experiences to build their efficacy in regard to teaching mathematics. These experiences should occur prior to culminating experiences such as student teaching and should include additional opportunities to build teaching self-efficacy and preservice teachers' confidence in their ability to powerfully and positively impact student learning. It is just simply not enough to put them in a classroom to observe the teaching of mathematics. Preservice teachers must show how they can make an impact and be given the opportunities to do so.

There are many future research directions that have arisen from the findings of this study. First, conducting interviews of preservice teachers with high and low mathematics self-efficacy and teaching efficacy should provide researchers with deeper insight into the attitudinal and dispositional differences between these groups. Additionally, a longitudinal study could be conducted where new teachers are administered the surveys used in this study to determine if experience, as we hypothesize, significantly influences beliefs about teaching ability and impact on student outcomes. And if so, how swiftly do these attitudinal changes occur? Lastly, it would be interesting to expand this study into other content areas such as literacy, science, and social studies.

Based on what we know about early childhood teachers, their feelings toward mathematics, and the importance of mathematics for young children, it is imperative that this line of research continues. It can provide valuable information, so teacher preparation programs can provide the necessary training to produce the highest quality early childhood teachers possible. It is imperative that teacher educators and preservice teachers work together toward this goal. Future early childhood teachers must be taught the importance of mathematics for their students and must learn to believe that they are capable and important role players in young children's understanding of mathematics.

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Re-examining Test Item Issues in the TIMSS Mathematics and Science Assessments

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As the largest international study ever taken in history, the Trend in Mathematics and Science Study (TIMSS) has been held as a benchmark to measure U.S. student performance in the global context. In-depth analyses of the TIMSS project are conducted in this study to examine key issues of the comparative investigation: (1) item flaws in mathematics and science; (2) inability to reflect item score differences between adjacent grades; (3) ambiguity of the test items behind nonrandom guessing; and (4) unfair comparisons resulted from inconsistent item difficulties across the nations. The TIMSS item checking could help education stakeholders understand more profound assessment issues through the information triangulation.

In June 2009, President Barack Obama pledged a total of $10 billion education investment through the "Race to the Top" initiative (Hamilton, 2009). To justify accountability of the federal spending, politicians were quick at citing educational studies in core subject areas, such as the *Trends in International Mathematics and Science Study* (TIMSS). In his March 2009 speech to the Hispanic Chamber of Commerce, President Obama announced that "In eighth grade math, we've fallen to 9th place"—ninth place was indeed the U.S. rank (among 46 nations) for the 2007 TIMSS administration (Bracey, 2009).

The TIMSS findings gained more public attention because of its status as the latest project among a series of comparative education studies (Mullis & Martin, 2006). Before TIMSS, the International Association for Evaluation of Educational Achievement (IEA) completed two rounds of international mathematics and science research during the 1960s–1980s (Hanna, 2000). TIMSS was originally named the *Third International Mathematics and Science Study* following the Second International Mathematics Study and the Second International Science Study (Garden & Orpwood, 1996). Although it was difficult to fund the past projects during the Cold War (Purves, 1987), "TIMSS differed from earlier IEA studies in another important respects: it was well funded, principally by the U.S. National Center for Education Statistics and the National Science Foundation" (Mullis & Martin, 2006, p. 8). As the largest comparative project in mathematics and science education, TIMSS billed the U.S. taxpayers over $51 million in the late 1990s (Bracey, 1998). When it was established as a regular report card of comparative education (Kelly, 2002; Wagemaker, 2008), additional support was provided for TIMSS 2003 and 2007 data collection. Accordingly, quality assessment is needed to justify the return of federal investment from this ongoing and expensive project.

Research Questions

Whereas the TIMSS data can be employed to study various education systems around the world, "explanatory models, no matter how sophisticated, are only as good as the instruments derived to inform them" (Murphy, 1996, p. 231). In the past, standardized tests were used widely in comparative research (see Lokan, 1999; Wolf, 1994), but that approach seemed inadequate for demonstrating mathematical proofs and/or describing the scientific reasoning process (Zuzovsky, 1999). To address this concern, "Three types of achievement items were included in the item pools for TIMSS: multiple-choice items; free-response items . . . ; and performance tasks" (Garden & Orpwood, 1996, p. 2). Still, the improvement was limited to the rubrics coding scheme (Angell, Kjaernsli, & Lie, 2000). Consequently, Harlow and Jones (2004) pointed out:

> We question the usefulness and quality of data from large-scale summative assessments on their own to represent student scientific understanding and conclude that large scale written test items, such as TIMSS, on their own are not a valid way of exploring students' understanding of scientific concepts. (p. 221)

Given these technical issues behind the TIMSS data interpretation, the purpose of this investigation is to examine validity of the TIMSS results using the released test instruments and public databases from the TIMSS public website (http://timss.bc.edu). Questions that guided this inquiry are:

1. Are there any scientific or mathematical flaws in TIMSS test items?
2. Are these items designated at a proper difficulty level with sufficient discriminative power to differentiate student performance between adjacent grades?
3. Does the TIMSS Item Response Theory (IRT) model, with or without the guessing parameter, fit the student performance across nations?

Literature Review

Since the mid-1990s, TIMSS has resulted in four rounds of reporting from its 1995, 1999, 2003, and 2007 surveys over around 50 participating countries (e.g., Beaton et al., 1996; Martin, Gregory, & Stemler, 2000; Mullis, Martin, & Foy, 2008; Mullis, Martin, Gonzalez, & Chrostowski, 2004). According to Mullis and Martin (2006), the reason to start TIMSS in the 1990s partially "came from the recent breakup of the Soviet Union, which resulted in a host of newly independent countries from the Central and Eastern Europe anxious to participate in a study that promised to provide data to guide the revitalization of their education system" (p. 7).

To reduce student burden, no lengthy booklet was employed in the TIMSS mathematics and science testing. Hence, each student only encountered a small portion of the test, and the IRT model was employed to assess student achievement (Foy, Galia, & Li, 2008). A one-parameter IRT model was initially used for scaling mathematics and science performance in 1995 without considering the effect of guessing. Later on, a three-parameter IRT model was introduced in 1999, including rescaling the 1995 student performance on multiple-choice items. The three-parameter model covered *item difficulty*, *guessing*, and *discriminative power* (Gonzalez, Galia, & Li, 2004). Although TIMSS items were endorsed by a Subject Matter Advisory Committee that included "distinguished scholars from 10 countries" (Beaton et al., 1996, p. A9), concerns on the item quality did not seem redundant. As Linn (2002) recollected,

> One such problem identified by Wang (1998) is the following: 'A glass of water with ice cubes in it has a mass of 300 grams. What will the mass be immediately after the ice has melted? Explain your answer' (Lie et al., 1996, p. 11). The keyed answer is 300 grams, supported by an explanation such as 'The ice changes into the same amount of water.' As Wang notes, this answer and explanation is correct if evaporation is ignored, but if a student takes evaporation into account, an answer of 'Less than 300 grams' is clearly defensible, but would not receive credit. (p. 44)

The item flaw remained in the most recent TIMSS 2007 project. Whereas the aforequoted issue dealt with an ice-melting process, a similar problem can be found from a new item on a water freezing process. The item labeled S022281 in the TIMSS 2007 project reads,

> A tray containing 300 grams of water is placed in the freezer to make ice. What is the mass of the ice after the water freezes?
> (Check one box.)
> ☐ More than 300 gm
> ☐ 300 grams
> ☐ Less than 300 gm
> Explain your answer.

Under the mass conservation principle, the mass of the ice should be 300 gm when the water evaporation is negligible, and thus, the second box could be checked as a correct answer. Or, with consideration of the evaporation effect, the ice mass could be "Less than 300 grams," which made the third box correct. In either case, given the 300 grams of water, it would be impossible to obtain the ice mass "More than 300 grams." Thus, the first box becomes the only wrong choice left.

Nonetheless, the TIMSS 2007 grading rubrics treated the first box as an acceptable choice as well. The explanation was based on a pretext of trapped air within the ice. This rubric was problematic because the trapped air, if existing, would keep its gaseous status—no chemical reaction occurred to covert the *air mass* into the ice mass. Thus, the ice formation solely came from the water freezing, regardless of the possibility of air trapping.

By making all three check boxes admissible, the item designer has compromised discriminative power for this item. Because a random guessing could earn the same score, this item seemed to have nothing to do with academic achievement. Therefore, treating all answers admissible, including the one unjustifiable, has inevitably contributed to the score inflation from the test grading.

Perhaps the impact from one item was negligible. But the gap among some countries was not large enough to endure the impact from the item misgrading. As Harlow and Jones (2004) pointed out, "Much of the media-generated publicity on the TIMSS results has ranked countries in order of achievement. However, the achievement scores for some countries were so close that ranking them could be misleading" (p. 221).

In addition, because not all TIMSS items were released at the TIMSS website (http://www.timss.org), no one can tell the exact number of TIMSS items with those scientific and measurement flaws. Given the policy implication derived from the TIMSS project, it becomes clear that the test item examination is needed to ensure a meaningful interpretation of the country rankings from international comparisons.

Method

The Item Response Theory (IRT) and the Classical Test Theory (CTT) are two major paradigms in educational and psychological measurement. The IRT model aligns student ability and item difficulty on the same metric so that the correct answers represent better student achievement (Hambleton, Swaminathan, & Rogers, 1991). Identification of the item features depends on inclusion of psychometric parameters that describe the effect of guessing, item difficulty, and discriminative power (Wright, 1992). In contrast, the CTT model is built on the relationship between observed scores and true scores (Novick, 1966), regardless of the parameter choice.

Altogether, those models provide complementary frameworks to guide test development (Allen & Yen, 2002). In particular, the CTT model is employed to support the inquiry of the first research question. To validate TIMSS results, systematic errors (E) are examined to detect scientific and mathematical flaws. Based on the relationship between the true score (T) and the observed score (X) (Novick, 1966),

$$X = T + E$$

we have $E = X - T$. Thus, X becomes a valid indicator of T when E is minimized according to the CTT model.

The second and third research questions are further investigated under the IRT paradigm. For a comparative study like TIMSS, the item discriminative power can be examined on the test outcomes between adjacent grades. Because the TIMSS 1995 survey covered the adjacent grade testing at the elementary and middle school levels, student performance can be compared at the adjacent third/fourth and/or seventh/eighth grades within the same country. As students learn more at an upper grade (i.e., the fourth and eighth grades), their average score should be higher than the scores of their peers at a lower grade. Hence, research question 2 can be disentangled through computing the item score differences between adjacent grades. Sorting the student scores by country, the item discriminative power can be reconfirmed by the differentiation of student performance within the same education system.

In terms of the item difficulty, the country rankings could remain valid if the difficulty level is equally skewed across all nations. Otherwise, an unfair comparison could occur if an item difficulty was inconsistently set for policy or linguistic reasons unrelated to mathematics or science education. In this study, qualitative examinations are conducted on these released TIMSS items to detect their uneven difficulty levels embedded in these contextual differences across the nations.

Although the TIMSS 1995 survey excluded the guessing parameter from the IRT model (Martin & Kelly, 1998), TIMSS 1999, 2003, and 2007 projects included the effect of guessing in the multiple-choice test scoring. The model choice needs to be justified through examining the item structure and the percentage of correct responses behind the random guessing (research question 3). TIMSS items are also examined on their scientific or mathematical ambiguity that forced students to guess an answer deliberately. The consequence of guessing is demonstrated by the controversial country rankings derived from the item performance.

In summary, all three research questions are identified and analyzed under the general framework of the CTT and IRT models. Whereas research question 2 is quantitatively addressed through the checking of student scores between adjacent grades, the content analyses are qualitative in nature, and have been proven useful to in-depth analyses of various test items (Wright, 1992). The quantitative results are described in the *Data Analysis* section, and the qualitative findings are presented in the *Discussion* section.

Data Analysis

To verify whether TIMSS scores reflect the achievement gap between the lower and upper grades, TIMSS 1995 databases from the third/fourth and seventh/eighth grades have been analyzed to identify the score difference in each participating country. Table 1 contains the number of items with the issue of reporting a higher average score at the lower grade.

Since the adjacent grade comparison was made within the same education system for each country, upper level students studied more mathematics and science curricula than their peers at the lower grade. However, the results in Table 1 seem to contradict a fundamental assumption of education—students who have more preparation will get higher test scores than those with less preparation (Rotberg, 2003).

Table 1
Number of Items Resulting in Higher Average Scores at the Lower Grade Level

Country	Number of Items with Higher Average Scores at the Lower Grade	
	3rd vs. 4th grades	7th vs. 8th grades
Australia	4	12
Austria	7	34
Belgium (FL)*		131
Belgium (FR)*		57
Canada	1	19
Colombia*		57
Cyprus	5	38
Czech	4	29
Denmark*		21
England	5	25
France*		15
Germany*		40
Greece	7	18
Hong Kong	9	41
Hungary	4	22
Iceland	6	43
Iran	12	60
Ireland	2	31
Japan	7	25
Korea	16	50
Latvia	7	12
Lithuania*		6
Netherlands	2	58
New Zealand	4	11
Norway	2	21
Philippines		81
Portugal	7	24
Romania*		30
Russia*		20
Scotland	8	10
Singapore	9	24
Slovak*		30
Slovenia	5	28
South Africa*		102
Spain		20
Sweden*		39
Switzerland*		25
Thailand	15	32
United States	2	22
Total no. of occurrences	150	1,364

*Those countries did not participate in the 3rd/4th grade investigation.

In addition, Table 1 showed that the reversed results seemed more severe in the seventh/eighth population than in the third/fourth population. As the content becomes more advanced at the seventh/eighth grades, perhaps TIMSS researchers need to be more mindful in designing and improving the test items for middle school students. The student perspective is important because the validity concept refers to the appropriateness of the test outcomes for a particular student population (American Educational Research Association, American Psychological Association, & National Council on Measurement in Education [AERA, APA, & NCME], 1999). As a member of the TIMSS Subject Matter Advisory Committee, Fensham (1998) acknowledged that no one in that committee had investigated what the students thought about the tests and the testing as a whole.

Discussion

To triangulate the empirical evidence from the TIMSS data analysis, specific contents are investigated in this section to demonstrate scientific or mathematical flaws in some of the released TIMSS items. In addition, the test difficulty is examined on its consistency across nations to ensure the fairness of the score comparison. The impact of guessing is further disentangled to reveal the uncertainty of student performance embedded in the TIMSS assessment.

TIMSS Items With Scientific/Mathematical Flaws

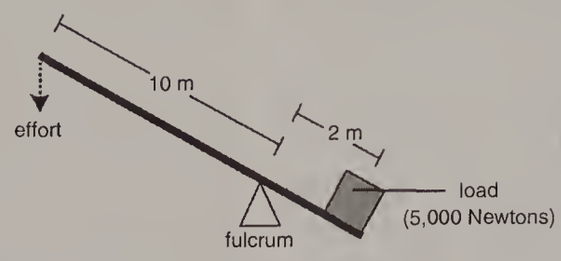
Contrary to the water-freezing item (S022281) that did not indicate a wrong answer, the following item from TIMSS 2008 could confuse good students with no correct answer. Thus, "crossed out, erased, stray marks" was observed in student responses (Foy & Olson, 2009, p. 48). For illustration, item S042244B was described with a graph (see Figure 1).

The load weight deals with the gravity force that has a composite acting point at the center of the load, rather than the top-middle point of the load. Unfortunately, the length of 2 m was drawn from the top-middle point of the load, which was to the right of the gravity center. After seeing the gravity force closer to the fulcrum, some students might wonder if the effort should be less than the formula answer of 1,000 Newton.

Without this visual inspection, students could have found the answer of 1,000 Newton by plugging in all given numbers into the formula. However, the subject domain was science (ID: S042244B) rather than mathematics. Since the load size was large enough to identify the gravity shift, the formula result might seem unfit to the graphic demonstration.

Peter and Joan read that six men could together lift a stone weighing 30,000 Newtons. Each man would then need to be able to lift one sixth of this weight (5,000 Newtons). They decided to work out how much effort each man had to exert on his wooden pole.

Peter added the length of each lever arm to Joan's diagram as shown below.



He looked up the following formula in a textbook:

$$\frac{\text{force exerted by load}}{\text{force exerted by effort}} = \frac{\text{length between effort and fulcrum}}{\text{length between load and fulcrum}}$$

How much force does each man have to exert to lift the block?

_____Newtons

Figure 1. Item S042244B of the TIMSS 2007 study.

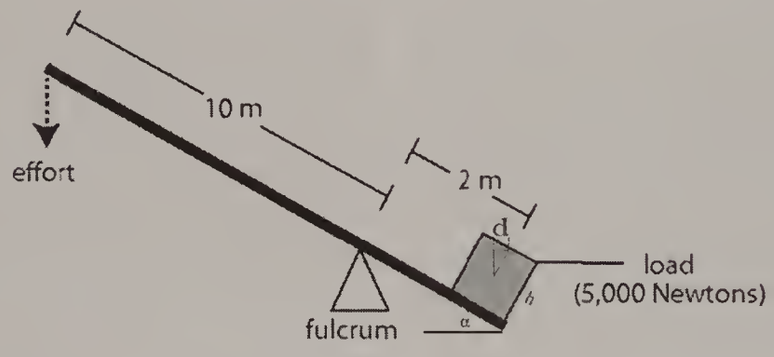


Figure 2. Adjustment of the gravity center.

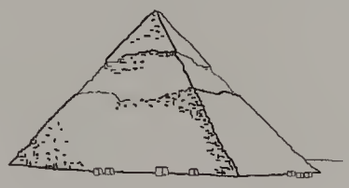
For better-prepared students with knowledge of trigonometry, the horizontal distance (d) related to the gravity shift can be configured in Figure 2. Given the load size (h) and the lever slope (α), the shifted distance is $d = \frac{h}{2}\sin\alpha$.

Since the load size and the level slope are not negligible in the graph (i.e., h $\neq$ 0 and $\alpha \neq 0$), the conclusion should be $d \neq 0$. Thus, 1,000 Newton should never be picked as a right answer with the existence of the length d. In reality, most textbooks ignored the load size to simplify the load representation as a mass point (e.g., Hagelberg, 1973; Millikan, Roller, & Watson, 1965), but the TIMSS test developers were not so mindful.

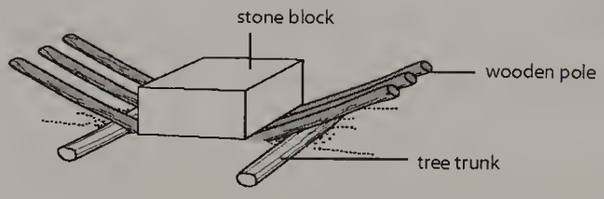
It should be noted that the wooden pole referred in item S042244B was introduced from Item S042244A under a historical context (see Figure 3).

The context of item introduction did not support scientific inquiry by the teenage students. In general, students often rely on a concrete visual checking to support understanding of scientific phenomena (Karplus, 2003). The question here has linked the *lever arm* to the *wooden pole*. However, the wooden pole did not appear to be weightless, nor did the question imply the weightless assumption. Thus, the graphic context conflicted with the formula understanding in item S042244B that had no account of the lever weight on either side of the equation.

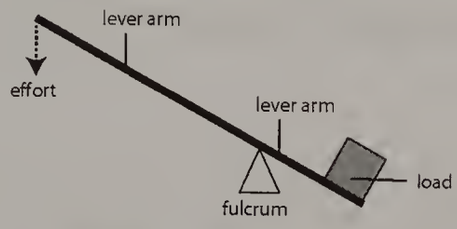
Peter and Joan are learning about the Great Pyramid of Cheops (Khufu) that is found in Egypt.



They wondered how the ancient Egyptians managed to lift the stone blocks to build the pyramid. They did some research on the Internet and found the diagram shown below.



Peter was not sure he understood the diagram so Joan drew a diagram to help him understand how the stone was lifted. Her diagram is shown below.



A. Match the parts of the Egyptian levers to the diagram of the lever Joan drew. One has been done for you.

Joan's Diagram	Egyptian Levers
Effort	Downward pull of the worker
Load	
Fulcrum	
Lever arm	

S042244_1

Figure 3. Item S042244A of the TIMSS 2007 study.

In TIMSS reporting, science was split into sub-domains, such as physics and chemistry, to categorize TIMSS items (Martin et al., 2000). However, the content classification did not seem to be mutually exclusive. For example, the mass conservation principle was double-classified into the content of physics (item S022281) and chemistry (item S042106). Whereas item S022281 was based on a water freezing process, item S042106 involved a substance-dissolving process (see Gonzales et al., 2008, p. B-13).

The negligence was not confined in science items. For illustration, the following item (ID: M031106) indicates that the so-called correct responses in TIMSS might not be so correct in mathematics (see Figure 4). Since it was specified in this item that "One digit could not be read," the missing digit should be one digit to conform to the question, "What is the missing digit?"

But that was not the way of student grading in TIMSS. The rubrics gave full credit to answers 2 and 527. Whereas, 2 was an accurate one-digit answer, 527 seemed to imply less attention on the question reading. Consequently, one could wonder if stricter teachers would consider the 527 answer as a careless mistake in a classroom setting.

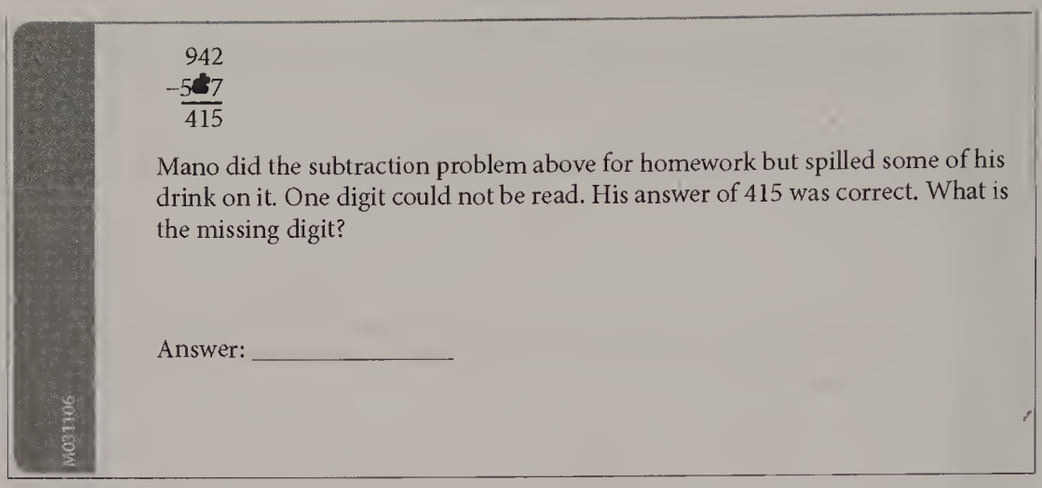

942
−5■7
415
Mano did the subtraction problem above for homework but spilled some of his drink on it. One digit could not be read. His answer of 415 was correct. What is the missing digit?
Answer: _____
M031106

Figure 4. Item M031106 of the TIMSS 2007 study.

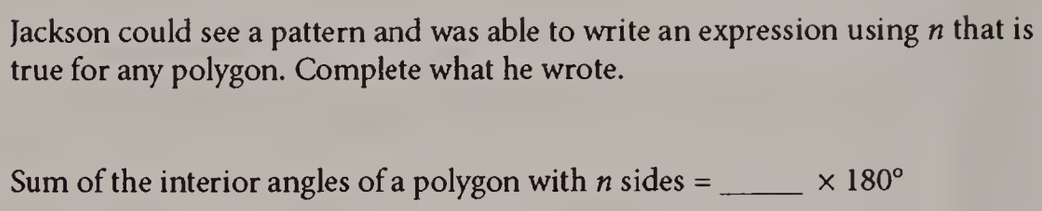

Jackson could see a pattern and was able to write an expression using n that is true for any polygon. Complete what he wrote.
Sum of the interior angles of a polygon with n sides = _____ × 180°

Figure 5. Item M042301C of the TIMSS 2007 study.

As another example, item M042301C demonstrated similar carelessness in the TIMSS 2007 project (see Figure 5). In this question, the grading rubrics indicated that the underline space can be filled out by "n-2 with or without brackets." Although the brackets did not seem to matter in the rubrics, they made a meaningful difference in mathematics. Without being too picky on the student response, it is prudent to conclude that not all correct answers in TIMSS have the same level of "correctness."

TIMSS Items With Uneven Difficulty Levels

Several researchers examined TIMSS items prior to the TIMSS 2007 project (e.g., Harlen, 1996; Harlow & Jones, 2004; Murphy, 1995; Wang, 1998). Harlow and Jones (2004) reported that "incorrect responses were not necessarily an indication of a lack of knowledge of a concept; sometimes they were due to misinterpretation of a question, a word, a phrase or a diagram" (p. 234). The issue of uneven difficulty level has been found in the following items from TIMSS 2003 (see Figure 6).

Unfortunately, the phrase "the first 20 degrees" was not a commonly used structure for Hong Kong students. Instead, it would typically be said as "to cool 20 degrees" (i.e., there is no explicit words "the first"). As Harlow and Jones (2004) pointed out, many students in Hong Kong misread the question as "to cool to 20 degrees" instead of "to cool the first 20 degrees." Such a language barrier has caused the uneven item difficulty that made the result comparison unfair to Hong Kong students.

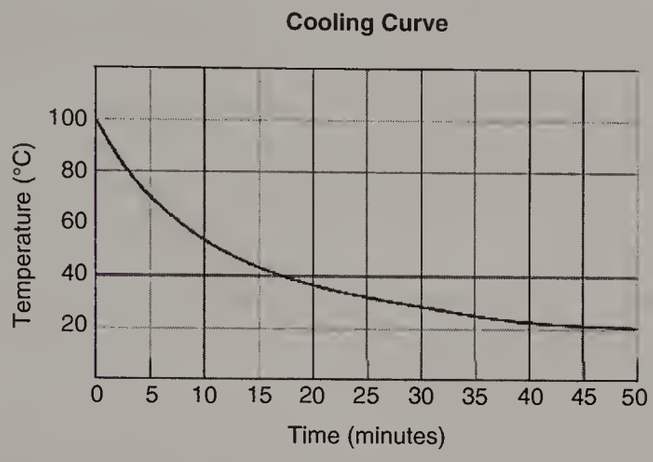
The uneven difficulty could also hinge on different education initiatives. For instance, "Calculators in Kindergarten" was adopted in many schools in the United States (e.g., Huinker, 2002; Judd, 2007). If calculators were allowed in TIMSS testing, U.S. students could have done well in questions like "What is 3 times 23?" However, these easy items became somewhat difficult when a decision was made to prohibit the use of calculators (Martin & Kelly, 1996). According to Quirk (2005), the TIMSS testing practice caused bitter debate for the mismatch of student learning in school settings.

In summary, valid international comparisons should be grounded on fair treatments of students in the test administration. Although the intent of TIMSS assessment was on assessing student achievement in mathematics and science, contextual factors, such as the language difference and calculator exclusion, might have disadvantaged some students and supported others. The uneven difficulty may lead to a biased comparison of student performance in TIMSS reporting.

Uncertainty of Guessing Embedded in TIMSS

Guessing could be an easy approach to save student effort during the testing. With a small number of items in

A beaker of water which has reached boiling point is allowed to cool. The temperature of the water is recorded at five-minute intervals, and a temperature-time graph is drawn.



About how many minutes did it take for the water to cool the first 20 degrees?

Ⓐ 3
Ⓑ 8
Ⓒ 37
Ⓓ 50

M022135

Figure 6. M022135 of the TIMSS 2003 study.

the test booklet, TIMSS test was not designed to assess individual performance (Martin et al., 2000). TIMSS researchers either did not include the guessing parameter in the IRT model (Beaton et al., 1996), or only considered the guessing for multiple-choice items (Gonzalez et al., 2004; Li, 2009).

Through empirical data analyses, the random effect of guessing can be gauged by the percentage of correct responses (Wang & Calhoun, 1997). For example, a TIMSS 1995 item has four options (see Figure 7). Thus, the probability of obtaining a correct answer through random guessing is 25%. Across all TIMSS participating nations, however, only 21% of third graders and 23% of fourth graders answered this question correctly (http://isc.bc.edu/timss1995i/TIMSSPDF/BMItems.pdf). The low rate of correct responses seemed to suggest that this item was too difficult for these students. Thus, guessing became a viable option. However, TIMSS researchers chose to exclude the guessing parameter from the IRT model in the 1995 study (Beaton et al., 1996).

Had the guessing parameter been included, the IRT model only took care of random guessing for multiple-choice items. It would be unrealistic to assume the guessing effect solely for multiple-choice questions. Sometimes the guessing issue was derived from lack of clarity in any test items. For instance, the following question from TIMSS 1995 was not in a multiple-choice format (Item T-2 of http://timss.bc.edu/timss1995i/TIMSSPDF/AMitems.pdf):

> What is the smallest whole number that you can make using the digits 4, 3, 9, and 1? Use each digit only once.

The number making could be (9-4-3-1), which led to a whole number of 1 as the answer. But the expected answer

K7. A thin wire 20 centimeters long is formed into a rectangle. If the width of this rectangle is 4 centimeters, what is its length?

A. 5 centimeters

B. 6 centimeters

C. 12 centimeters

D. 16 centimeters

K-7

Figure 7. Item K7 from http://isc.bc.edu/timss1995i/TIMSSPDF/BMItems.pdf.

Work is done when an object is moved in the direction of an applied force. A person performed different tasks as shown in the diagrams below. In which diagram is the person doing work?

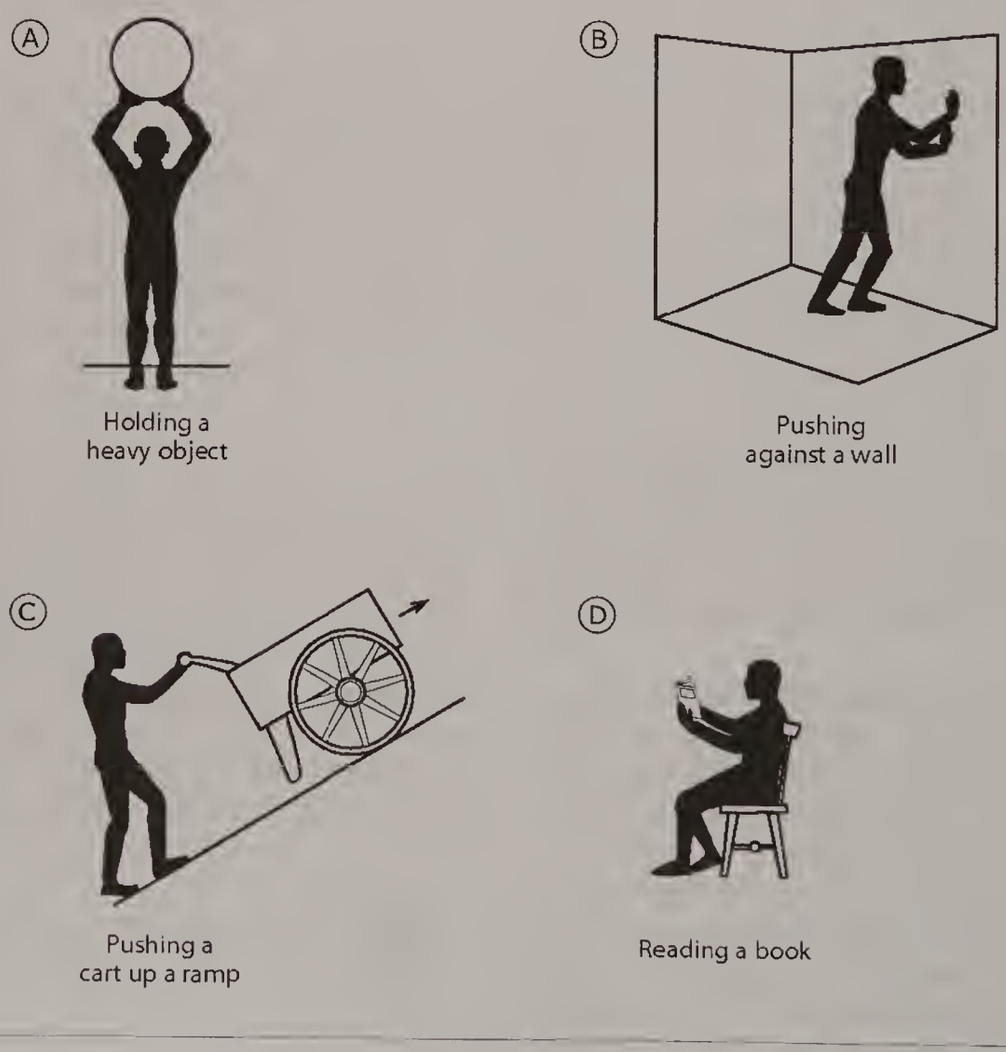


Figure 8. Item S032425 of the TIMSS 2007 study.

was 1349. Without requiring a 4-digit number in the question, "1" could be a whole number smaller than "1349." Because of the item ambiguity, guessing might be needed to reach an open-ended answer for this question. But "1" was classified in the TIMSS rubrics as an incorrect answer.

Similarly, item S032425 in Figure 8 was treated as an exemplary question in a TIMSS 2007 report (Gonzales et al., 2008). Clearly, choice C was an answer to this question since the cart was pushed to move in the diagram. But it was unclear whether the reading option implied "reading aloud." This ambiguity could lead students to make a wild guess. If the reading sound can be heard, work could be done in diagram D because air has been moved in the direction of the applied force. According to Crawford (1968), sound "in an average conversational tone emits about 100 erg/sec of sound energy" (p. 199). Treating the sound as a longitudinal wave through the air, it would be difficult to imagine the energy transmission without any work completion (Atkins,1970; Eisberg & Lerner, 1981).

Are there any consequences from this vague item on the student side? The TIMSS 2007 data also showed that students from Japan, Hong Kong, and Chinese Taipei were all scored lower than their U.S. counterparts on this test item (Gonzales et al., 2008, p. B-14). This result contradicted the general trend of the TIMSS findings that placed students from the East Asian regions above their peers from the United States in academic achievement. Perhaps, this abnormal outcome was resulted from the fact that choice D received no credit from the TIMSS 2007 project.

In conclusion, TIMSS researchers need to continue improving the item quality on multiple dimensions. Scientific and mathematical errors should be avoided to enhance validity of the test outcome. Adjacent grades should be re-assessed to disconfirm the lack of discriminative power illustrated from the TIMSS 1995 results. Ambiguity of the test items should be eliminated to curtail biases from the inadequate consideration of the legitimate guessing. Difficulty levels should be maintained appropriately and consistently across the participating nations to ensure a fair comparison of student performance in mathematics and science. Those suggestions are firmly based on the CTT and IRT paradigms, and empirically supported by the TIMSS 1995 data analyses between adjacent grade levels.

It was claimed in a TIMSS report that "The [test composition] process incorporated the expertise of mathematics and science educators and test development specialists from all over the world" (Ruddock, O'Sullivan, Arora, & Erberber, 2008, p. 13). As "TIMSS continues to be widely recognized as the most influential study of its type" (Wagemaker, 2008, p. 2), those past items, including the problematic ones identified in this study, could be used again in local benchmark studies (e.g., Tananis, Chrostowski, Bunt, Seeley, & Tamler, 2002). Similar to a speedometer checking to avoid inaccuracy in speed measurement, the in-depth examination of TIMSS items could help education stakeholders understand more profound assessment issues behind the benchmark adoption.

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Author's Notes

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The Influence of Science Summer Camp on African-American High School Students' Career Choices

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This study explored if a weeklong science camp changed Louisiana African-American high school students' perception of science. A semi-structured survey was used before and after the camp to determine the changes in science attitudes and career choices. Among the perceived benefits were parental involvement, increased science academic ability, and deepened scientific knowledge. These perceived benefits influenced the identities that students constructed for themselves in relation to science in their lives. Students who reported doing well in school science courses believed that science was more relevant to their lives. Female students who cited doing well in science reported less parental involvement in their schoolwork than males. This study draws attention to gender differences in science and to designing informal science learning experiences for African-American high school students that can change attitudes toward career choices in science-related fields.

Motivating school children to pursue careers in science has been an abiding concern in American education. Relative to students in other industrialized countries, their American counterparts have been doing significantly less well in math and science. Fewer students are choosing science as majors not to speak of as a career. Their math and science scores in standardized tests have been falling among secondary students (National Assessment of Educational Progress [NAEP], 2009). This is worrisome as the world is rapidly moving toward knowledge-based economies with a high quotient of science (and math). With fewer science graduates in the pipeline, America runs the risk of becoming less competitive and economically less powerful (NRC, 2009).

The reasons why students do not show greater interest in science is an urgent matter and has been the subject of a great amount of educational research yielding a wide range of factors. These include ethnicity, socioeconomic status (SES), gender, K-12 experience with science, early ideas about science and scientists, and family and peer influence (Barab & Hay, 2001; Catsambis, 1995; Ferguson & Mehta, 2002).

There seems to be a clear association between science interests and ethnicity. Euro-Americans score the highest in science followed by Asian Americans. African-Americans and Hispanic-Americans score at the bottom (National Academy of Sciences, 2005). The findings of several studies by the Center on Education Policy stated that Black and Hispanic students are more likely not to choose a career in science. This report (National Academy of Sciences, 2005) also noted that science scores have been consistently dropping since the 1990s, especially those of underrepresented minority students. During this period, the total number of college students, regardless of ethnicity, pursuing careers in science dropped as well. The disparity between Black and Hispanic students and their White and Asian students continues to widen (Catsambis, 1995, National Center for Education Statistics, 2001; Shannon & Bylsma, 2003).

However, attitudes toward science and disparity in science scores are not entirely related to genetic factors as claimed in several studies. An ensemble of factors such as parenting styles, teachers' readiness to teach science, ethnicity, socioeconomic status, resource inequities between high- and low-achieving schools, and low teacher expectations of minority and female students contribute to the decline (Catsambis, 1995; Jones, Howe, & Rua, 2000). Gonzales et al. (2009) has found that students from higher socioeconomic backgrounds tend to have higher mean science achievement scores than those from lower socioeconomic backgrounds.

There is virtual consensus that K-12 science experience plays a crucial role in attracting or extinguishing further interest in science (Catsambis, 1995; Jones et al., 2000; Newton & Newton, 1998). K-12 education is where attitudes and beliefs about science and scientists are formed (Baykul, 1990; George, 2006; Majumdar, Rosenfeld, Rubba, Miller, & Schmalz, 1991). It is at this level that children will decide the answers to questions such as: Is science interesting and fun? Can a girl become a scientist? Are all scientists nerds? Can one be a scientist and still have a family? Family and peer involvement in children's

learning, SES, and school experiences can positively or negatively shape the answers to these questions (Baykul, 1990; George, 2006; Majumdar et al., 1991).

Baykul (1990) showed that although children enjoy and have an interest toward science in their primary school years, they lose their motivation and start to dislike science classes in their middle-secondary school years as a result of perceiving science classes to be difficult. Raizen (1991) reported that middle-school science instruction is often nothing better than an extension of elementary school instruction. Methods of science instruction in middle school might be a major reason for the gender gap in science achievement. Jones et al. (2000) found that male and female students often have very different experiences in science classrooms. Males dominated in conducting experiments, carrying out demonstrations, and manipulating equipment, while girls remained relatively passive. By high school, females tend to avoid science classes and shift to social sciences. The NAEP (1997) reported that male students scored higher in science than females during high school.

Females may score lower in science testing because they experience school and society differently. Eighth grade is when they become exposed to future career choices. It is also a critical time in the social development of girls, including their emerging view of what is socially accepted and what is possible for them in their future (Rakow & Barufaldi, 1991; Ramos & Lambating, 1996). After a series of in-depth interviews of girls who did choose science, Baker and Leary (1995) reported that their choice was the result of the influence of a complexity of factors: encouragement by the family, peer approval, and engaging in extracurricular activities such as doing science projects at home, reading about science, or watching science-related television shows. Females also evince a preference for "helping professions." Catsambis (1995) found girls rejecting physical sciences because these were not viewed as helping others in contrast to the way they perceived social sciences.

It is evident that encouraging students to pursue science calls for early and multipronged intervention strategies including economic and work place reform so parents are able to be more involved in their children's education; equipping and staffing K-12 classes with proper science teaching materials, and trained teachers; and greater media visibility of role models of scientists who are women/Hispanic-American/African-American/Asian-American. However, most of such remedial measures are unlikely to be operational anytime soon (Gregory & Mosley, 2004; Johnson & Kritsonis, 2006).

As a remedial measure that can be implemented in the short term, summer science enrichment programs are proving to be effective. They can improve science self-efficacy and engender a positive attitude to science (Barab & Hay, 2001; Fields, 2009; Strike & Posner, 1992). These programs provide immersive and relatively informal environments where young people spend periods of time outside of the normal classroom in scientific experimentation, investigation, and critical thinking. These types of programs, if well designed, can provide experience in learning that are rarely accessible in the traditional classroom and can focus on aspects of science education that may be ignored or undervalued by traditional curricula (Reardon, 2002). Similar claims were made by several researchers about effectiveness of one weeklong outdoor residential camps. According to these studies, one week summer camp helped to improve social comfort and self-efficacy in children and youth because of the social encounters, new activities, independence, and leadership opportunities provided by summer camps (Colyn, DeGraaf, & Certan, 2008; Fields, 2009; Gilmour & McDermott, 2008; Thurber, Scanlin, Scheuler, & Henderson, 2007). In the state of Louisiana, only a small percentage of the population has an education beyond high school, and few go to college (Louisiana First-Time College Freshmen State Report, 2009). Thus, there is a need for special supplemental programs to motivate students to begin planning and to prepare for post-secondary education in science in Louisiana.

Louisiana schools offer several extracurricular science programs to assist students to be successful in high school and college. In general, it has been found that students become more interested and productive in these programs than in the regular school (Reardon, 2002). One program that serves this purpose is LAGEAR UP. It selects academically at-risk 9th–12th graders from those reported in the Louisiana First-Time College Freshmen State Report (2009). The screening process involves eighth-grade standardized test scores, teacher recommendations, and behavioral considerations. Most students invited into the program have struggled academically in school but do not have a history of behavioral problems. None of these students receive special education services.

For this study, three separate weeklong LA GEARUP science summer camps for high school students from south Louisiana over three years were surveyed to find if the camp experience made a difference in the students' overall attitude toward science and possible career choices in science. The purpose of the study was to investigate if there was any change in students' attitude to and

perceptions of science eventually resulting in career making decisions in science. It hardly needs to be stated that the summer camps were never thought as substitutes for the regular schools, teachers, and counselors. They were viewed more as opportunities for participants to actually do science as scientists, and do it in a fun way, and thereby developing an interest in science. The science concepts presented during the camp were among those the students had already been exposed to in their school science classes. The rationale for this was to present already familiar concepts in a different and fun way. The fear and antipathy to science that school students commonly feel could thus be overcome and changed into a positive attitude. Science learning can take place in all manner of venues. For example, local bayous were used to determine water quality; an experiment with Mardi Gras beads was used to understand Newton's laws of motion; household plastic to develop the concept of polymers; and tennis balls and coat hangers to prepare silly hats for identifying the center of gravity. The concept of static electricity was introduced by using foil paper, wool cloth, and Styrofoam™ blocks.

Project Description

The science summer camp (as a part of LAGEAR UP) aims to provide early exposure to the college experience for ninth- through 12th-grade students and to instill the belief that college education was possible for them. The expected goal of the project was to promote science career as an option through stimulating learning opportunities. Every summer, LAGEAR UP offered twice a one week-long science summer camp. During the camp, the students experienced science as "common sense" by manipulating items used in day-to-day life.

There was an average of 52 students in attendance at each session of the camp. At the end of each class day, the participants were required to create a concept map of the topics they learned using Inspiration software (Inspiration Software Inc., Beaverton, OR). Inspiration helps in constructing, organizing, and presenting in-depth understanding of the concepts by interconnecting them visually (Novak, 1994). Concept map is a versatile science education tool for investigating students' understandings of concepts. These maps enable the teachers to assess the students' grasp of topics they have learned (Novak, 1994). As an assessment tool, student-constructed (as opposed to fill-in-the-blank) concept maps provided evidence of changes in knowledge over time (Cockcroft, 2008).

Students also performed field investigations. In this case, they examined the quality of bayou water and its relationship to the local economy. Field investigations are a hands-on way of understanding how to design and conduct scientific experiments (Ryken, Foreman, Tudor, & Koehler, 2008). The participants formulate their own research questions so that they will be more likely able to construct meaningful ideas of the nature and methods of science (Dobson, 2008). Student-generated projects facilitate student ownership of the research project and promote creativity (Fields, 2009). The students were provided with Image Probes (Newark/Element14, Chicago) to determine salinity, pH, temperature, and dissolved oxygen. They entered the data collected from the bayou in Microsoft Excel worksheets, analyzed them, created charts and graphs, and made a Microsoft PowerPoint presentation of the findings to the entire camp.

The students worked in small groups as they participated in various experiments, research data gathering, preparing concept maps, and the final PowerPoint presentation. In each area, they used a rubric that was provided to them at the beginning of each activity, and each group was actively guided by the group counselor. All activities were constantly monitored by the instructors and the counselors. The expectations were that through the processes and activities described above, the students would acquire social and communication skills, learn about the scientific method, and apply its general structure to a wide range of practical problems. Through presentation, they would be encouraged to develop a personal position about their topics. In having to respond to the audience during presentation, they would learn to present arguments using evidence. To ascertain if their understanding of the topics increased, their concept maps were examined for correct use of scientific terminology and the connections made between the concepts. Each day, their maps were viewed by the instructors and counselors to ascertain whether the arrangement of the concepts were forming a web, following a logical format, and establishing a hierarchy of the concepts. The goal of the project was not to set standards too high for the students to reach but to see how interested they were becoming in the process (Kane & Staiger, 2002).

Methods

A 21-item science and career questionnaire was developed using a five-point Likert-type scale. A number of items were derived from various attitude scales (Francis & Greer, 1999). The survey also asked for demographic information and one question pertaining to the letter grade that the participants usually made in science courses at school. The survey was administered over three summers (2006, 2007, and 2009) to each session at

the beginning and end of the summer camp. The questionnaire was constructed by a team of professors from the teacher education and biological science departments at the university hosting the camp. Following the recommendations made by a number of specialists in the field (Simpson & Oliver, 1985; Sjoberg & Imsen, 1988; Sjoberg, Mehta, & Mulemwa, 1995), the questionnaire was further reviewed by another group of professors from the same disciplines.

Four key influences (indices) on science attitudes were identified for the focus of the survey: parental involvement (PARI) in schooling, previous and current science involvement (SCII) at school and home, science relevance (SCIR) to daily life, and perceptions of one's science academic ability (SCIA). Survey questions specific to each index were created, and a composite index score was calculated (Tables 1–4). Reliability was determined by calculating internal consistency (Cronbach's alpha) of the entire survey, which was .67.

Results

The survey was administered to two sessions of students each summer before and after the camp. Each session averaged approximately 52 students, for a total number of 313 students. Of these students, 147 were male, and 166 were female. The gathered data were entered into SPSS version 17 (IBM, Armonk, NY). The mean, standard deviation, and percent of respondents for each index question who marked either "strongly agree" or "agree" are provided in Tables 1–4.

A 2 (pre/post) × 2 (gender) × 5 (grade) repeated measures analysis of variance (ANOVA) for each index was computed to determine differences in attitudes toward science. The within subjects factor was the pre-/posttest. The ANOVA was used to determine if attitudes changed from the pre-survey to the post-survey and if grades and gender influenced student's attitudes toward science.

For the PARI index, only one significant finding was found (Table 5). The interaction of gender × grade, $F(2, 2) = 3.47$, $p = .032$, revealed that females who reported receiving "B" grades in science scored lower on PARI ($M = 11.60$) than males receiving "B" grades in science ($M = 13.91$). No students in the survey reported receiving "A" or "F" grades. Therefore, female students who responded as doing well in science reported less PARI in their schoolwork than males.

For the indices SCII and SCIA, no significant statistical differences were computed. For the index SCIR, a significant interaction was computed between the variables gender and grade, $F(2, 2) = 3.61$, $p = .028$ (Table 6). Males who reported receiving "Ds" in science courses scored higher on scores of SCIR ($M = 8.78$) than females ($M = 6.87$) reporting "Ds" in science classes. A difference also existed on SCIR scores for the main effect of grade, $F = 4.05$, $p = .018$.

Discussion

It was hoped that a weeklong exposure to science experiments during science camp would lead to more

Table 1
Mean and Standard Deviation of SCII Index Questions (n = 313)

Survey Question	Pre-Survey		Post-Survey	
	Mean (*SD*)	% Agree	Mean (*SD*)	% Agree
I am a member of a science club in school.	2.42 (1.35)	23	2.55 (1.37)	30
I watch TV shows about science.	3.61 (1.36)	75	3.67 (1.38)	68
I keep up with the news by watching TV, reading newspapers, or browsing the Internet.	3.86 (1.23)	74	3.63 (1.39)	70
I enjoy working in a science lab and doing experiments.	4.02 (1.19)	81	4.14 (1.09)	79
I will be taking as many science classes as I can.	3.41 (1.27)	35	3.62 (1.30)	55
I would like to major in science in college.	2.62 (1.26)	21	3.64 (1.15)	52
I would like to become a scientist.	2.64 (1.24)	22	2.63 (1.24)	21
SCII score	22.39 (5.00)	—	22.55 (4.95)	—

SD = standard deviation.

Table 2
Mean and Standard Deviation of SCIR Index Questions (n = 313)

Survey Question	Pre-Survey		Post-Survey	
	Mean (*SD*)	% Agree	Mean (*SD*)	% Agree
Scientists are important people.	4.04 (1.08)	82	4.29 (1.00)	85
Many good things in my life are due to science and technology.	4.01 (1.20)	75	4.23 (1.08)	82
Doing well in science at school will open up different career options.	3.69 (1.02)	62	3.44 (1.24)	51
Majoring in science will give me the power to choose my salary.	3.22 (1.16)	36	3.13 (1.27)	39
We do not need to learn science in school.	2.13 (1.28)	18	2.21 (1.42)	20
I do not need science because I will never use it in my job.	2.57 (1.20)	17	2.44 (1.30)	20
In the summer break, I will get a job rather than attend science camp.	3.54 (1.13)	51	3.62 (1.18)	56
SCIR score	6.71 (3.51)	—	6.66 (4.22)	—

SD = standard deviation.

Table 3
Mean and Standard Deviation of SCIA Index Questions (n = 313)

Survey Question	Pre-Survey		Post-Survey	
	Mean (*SD*)	% Agree	Mean (*SD*)	% Agree
I plan on going to college.	4.40 (1.02)	84	4.37 (1.11)	86
I do well in my science classes at school.	3.84 (1.14)	72	3.96 (1.09)	72
Science is a very hard subject in school.	2.94 (1.34)	40	2.84 (1.33)	40
SCIA score	5.27 (2.56)	—	5.51 (2.46)	—

SD = standard deviation.

positive attitudes toward science and greater interests in science-related fields. The results of the study showed that students' attitudes toward science did change positively after the camp. The percentage of students who agreed "on planning on taking as many science classes as possible in the future" more than doubled. After the camp, more than half of the students indicated that they wanted to take more science courses. The percent of students planning on majoring in science in college more than doubled after the camp. Despite the fact that students' attitude toward science changed after attending the camp, the number of students wanting science as a career remained unchanged. One reason might be the perception of the scientist as the popular image of a mad scientist or as a geek or a nerd as portrayed in the media (Eugster, 2009). Besides, a week-long summer camp is perhaps not enough to affect their career choice.

Participants in this study might not see themselves pursuing a science-related career because of low grades obtained in high school science courses. In fact, George (2006) showed that children in their primary school years enjoyed science and had interest in it in their primary school years. But they lost their interest and motivation and started to dislike science classes in their secondary school years, perhaps as a result of perceiving science classes as difficult. These students chose social sciences tracks over science in their secondary school years. Newton and Newton (1998) also had the same insight:

Table 4
Mean and Standard Deviation of PARI Index Questions (n = 313)

Survey Question	Pre-Survey		Post-Survey	
	Mean (*SD*)	% Agree	Mean (*SD*)	% Agree
My parents/guardians encourage me to consider college.	4.00 (1.41)	69	4.02 (1.35)	72
My parents/guardians help with homework.	3.56 (1.29)	68	3.88 (1.30)	73
My parents/guardians have careers in science or engineering.	2.74 (1.50)	35	2.72 (1.42)	32
My parents/guardians want me to be a scientist/doctor/engineer.	3.09 (1.23)	37	3.15 (1.26)	38
PARI index score	13.27 (3.20)		13.67 (3.16)	

SD = standard deviation.

Table 5
ANOVA Summary of SCII Index

Source	df	MS	*F*	*p*
Between Subjects				
Gender (G)	1	32.37	.76	.38
Grade (R)	2	11.98	.28	.76
G × R	2	35.16	.82	.44
Within Subjects				
Pre/Post (P)	1	.08	.01	.91
P × G	1	5.30	.82	.37
P × R	2	3.87	.60	.55
P × G × R	2	.45	.07	.93

df = degrees of freedom; MS = mean square.

Table 6
ANOVA Summary of SCIR Index

Source	df	MS	*F*	*p*
Between Subjects				
Gender (G)	1	38.61	1.86	.17
Grade (R)	2	84.17	4.05	.02
G × R	2	75.14	3.61	.03
Within Subjects				
Pre/Post (P)	1	1.29	.15	.70
P × G	1	<.01	<.01	.99
P × R	2	2.66	.31	.73
P × G × R	2	2.66	.31	.73

df = degrees of freedom; MS = mean square.

> If you want them to develop a lasting interest in science, it was vital to capture children's imaginations before the age of 11. In other words, if the child hasn't enjoyed science prior to this age then the child may never enjoy science. The subject is then lost to them and makes little sense in secondary school.

Looking at the data from another perspective, we found that student grades in science may have played a role in their attitude toward science. The students' low grades in science clearly indicated little desire to pursue science. This finding provides evidence that low achievers' negative attitude toward science did not change even after the camp (Rennie & Punch, 1991). They did enjoy the experiments because those were "cool," but at the same time, they were intimidated by the idea of pursuing science as a career. The decision to choose science as a career requires changes in the students' priorities in life, which they are not ready to make (Majumdar et al., 1991). In this study, the association between perceptions and choices is very clear. The percentage of students who agreed "doing well in science at school will open up different career options" was almost the same as those who agreed "I would like to major in science in college."

Students' career choices were found to be strongly influenced by their parents' attitude and involvement in their lives. Whiston and Keller (2004) found that family may have stronger influence than teachers when it comes to children's career decisions. However, the role of parents was found to differ between male and female children. There is parental encouragement for boys and a

discouragement of girls for choosing science (Ji, Lapan, & Tate, 2004). In this study, only 35% of the students received parental support to choose science as a career. There was a significant interaction between the gender and grade variables. Girls reported low interest in science, irrespective of their grades in science subjects. But more boys showed a greater interest in science even when they obtained low grades in science subjects in school. This is in agreement with global data; in general, girls do not see themselves as pursuing science. This study reveals that girls' interest in becoming scientists drifts away as they get older due to parental discouragement (Bank, Slavings, & Bruce, 1990; Esther & Douglas, 1996).

This study illustrates the need for more research on parental perceptions and for programs that make parents aware of career information as well as their actual influence. Parents may see career choice as simply a process of trial and error that their children need to experience for themselves. In general, when children become curious about pursuing a particular career, parents who feel that they should not influence may appear aloof to their children, causing miscommunication. This aloofness may be due to the lack of knowledge about careers, a desire to instill independence in their children, or a fear of losing connection with their children. Regardless of their interpretations, parents need to be aware of their role in their children's career development.

It is obvious then that the point of strategic intervention to encourage students, specifically girls, to choose science as a career is the parents. Perhaps the initial step would be to understand the causes and the nature of parental aloofness or discouragement. Several actors can play an important role in this. Parent–teacher associations, school career counselors, and science teachers may engage with parents in conversation about their children, particularly girls in science. Women who have become scientists may be invited to the conversation to share their experience as role models. Local media may participate in this effort by profiling women scientists as well as those girls who have chosen science for a future career.

Conclusion

Overall, this study has found in the participants a mixed view of attitudes toward science. The students saw the value of science to society and the role of science beyond school, yet science was not a career preference because they perceived it as difficult. Many of them liked to perform science experiments but had no desire to be scientists.

Gender seemed to be a crucial factor in choosing science as career. Females tended not to choose science as career as opposed to males. It was shown in this study that parental influences play a strong role in shaping girls' attitudes toward pursuing science as a career.

Teachers may also play a particularly important role in influencing these girls to choose science (Myrick & Carrow, 1987). Equity of access and encouragement in mathematics and science is certainly necessary, but it is insufficient alone for improving the representation of women in science-related jobs.

This study did not investigate the role of peer pressure in career choices of either males or females. Further research in this area will give us more direction in determining the factors of students' career-making choices.

Nearly all the students in the camp were African-American. Our study shows that only 21% of the African-American students considered pursuing a major in science when they arrived at the camp. Why African-American students have shown little interest in science is not clearly understood. Several studies have found that African-Americans display a greater interest toward social service-related careers than do European Americans (Shipp, 1999). Their aversion to science needs to be better understood.

Perhaps school counselors need to play a more decisive role in developing and sustaining minority students' personal/academic science confidence before college. To better accomplish the mission, school counselors need to be adequately informed about what factors influence high school students' career choices and what approaches would best facilitate their career decision-making process. This could be done by providing students with a variety of role models in a variety of contexts. Counselors can also use critical life events as learning experiences to shape their future (Tang, Pan, & Newmeyer, 2008). They should work with community members to identify resources that would help students improve their career-related skills. Parents should be included in intervention plans as well. This might help mobilize their support for science.

In conclusion, summer camps like this provide an inclusive and threat-free environment where students' interaction with the instructors, staff, and counselors is likely to be more personal than in regular classrooms. This kind of environment may boost the students' self-confidence. This summer camp did not use students' grades as an indicator of success; instead, it helped them

to identify their strengths. This realization of personal strength by some of the students may encourage them to move forward, away from the ongoing downward spiral.

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Authors' Notes

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Keywords: Student attitudes toward science; African-American students; secondary school science; camp programs; summer programs; teacher attitudes; peer influence; career choice; teacher–student relationship; science process skills; scientific research.

A Cross-Cultural Lesson Comparison on Teaching the Connection Between Multiplication and Division

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This study compared one lesson across four U.S. "traditional" textbook series, two U.S. reform-based textbook series, and one Chinese mathematics textbook series in teaching the connection between multiplication and division. The results showed the differences across U.S. and Chinese lessons in both the teaching and the practice parts of the lesson across three dimensions (i.e., problem schemata, response requirement, and algebra readiness). In particular, the Chinese lesson's penetrating analysis or explanation of the topic is reflected in its deliberately constructed examples and wide range of problems (pertaining to problem types and difficulty levels) present in the teaching and practice sections of the lesson. None of analyzed U.S. lessons are comparable with the Chinese lesson with respect to the breadth and depth in teaching the topic. A deliberate emphasis, both arithmetically and algebraically, on problem schema acquisition as found in the Chinese lesson represents a promotion of symbolic or higher order of conceptual understanding. The findings are discussed within the context of teaching big ideas through problem schemata acquisition and the importance of symbolic level of conceptual understanding.

The performance of U.S. students in mathematics when placed in the international landscape has evoked many investigations to explore factors contributing to the differences found across different nations. Although "mathematics learning is a culturally scripted activity whose outcome is a function of interrelated factors and environments" (Wang & Lin, 2005, p. 10), curriculum and the learning opportunities it provides are strongly related to students' learning (Cai, Lo, & Watanabe, 2002; Schmidt, et al., 2001).

To date, two specific developments have come to heavily influence curriculum programs in mathematics education. One is the availability of newly developed reform-based curriculum materials/textbooks (e.g., math curricula developed through support from the National Science Foundation). The other development is that school districts are required to use a single curriculum that is supported by scientific-based evidence to ensure instructional quality in general/inclusive education classrooms. These two trends are an attempt to address the nonsuccess of schools to raise students' achievement scores (Remillard, 2005).

Cross-Cultural Perspectives

Many cross-cultural curriculum/textbook analyses have provided insights pertinent to curriculum/instructional design. As for curriculum standards, Schmidt et al. (1997) compared the mathematics and science curricula of the United States with those of 46 nations in the world and found that the standards in the U.S. curriculum were short of coherence and focus (Valberde & Schmidt, 2000). As for fine-grained textbook lesson analysis, Mayer, Sims, and Tajika (1995) conducted an in-depth analysis and comparison of lessons on addition and subtraction of signed integers between three seventh-grade Japanese and four U.S. mathematic textbooks. They found that there were many more worked-out examples with thorough explanations in the Japanese textbooks. Japanese textbooks used multiple representations (e.g., symbolic, verbal, and pictorial) and built connections among multiple representations. In contrast, the U.S. textbooks allocated more spaces to unsolved exercises. In addition, Japanese mathematics instruction placed more emphasis on problem-solving process (i.e., how to get the right answer) with complete explanations through solving a class of problems, whereas the U.S. textbooks seemed to assume that the student learns best through experiencing problem solving with student-centered hands-on activities (Mayer et al., 1995).

More recently, Xin (2007) discovered that U.S. students' performance profile may be directly related to the design of U.S. textbooks (e.g., work-out problems and practice problems presented in the textbook). Specifically, Xin (2007) examined the potential influence of learning opportunities on student ability to solve a range of word problem types by determining student success rate (i.e., item-difficulty measure) in relation to word problem distribution in adopted textbooks. The relation between adopted textbooks' word problem task presentation and student success rate in solving various problems suggest that U.S. participating students' ability to solve certain problem types better

than others may be directly related to the design of U.S. textbooks (e.g., unbalanced word problem distribution).

Focus on Big Ideas

Textbooks provide a foundation on which the holistic classroom mathematics curriculum is based (Li, Ding, Capraro, & Capraro, 2008). As such, it would be worthwhile to examine how textbooks teach "big ideas" that connect or integrate mathematical ideas to promote conceptual understanding and generalizable problem-solving skills. Connections, as one of the five *Process Standards* stipulated by the National Council of Teachers of Mathematics (NCTM; 2000), emphasize students' ability to recognize and understand how mathematical ideas are connected to each other and make a use of the connections among mathematical ideas.

In this study, we chose to analyze a lesson that addresses the connection between multiplication and division. Understanding the operations of multiplication and division and the connections between them is crucial (Van de Walle, 2004) for multiplicative reasoning, one of the foundational concepts for students to move onto higher level mathematics learning. Based on our knowledge, no existing research studies have looked at how textbooks teach the connection between mathematics concepts (multiplication and division in particular) with a cross-cultural perspective.

Purpose and Research Questions of the Study

The purpose of this study was to conduct a quantitative and qualitative analysis of the lesson content including modeling and practice sections, with regard to how the lesson facilitates or reinforces students' conception of multiplicative reasoning and the connection between multiplication and division. Specific research questions include (1) how the lesson provides opportunities for students to solve variously situated problems to facilitate knowledge construction and generalizable problem-solving skills (Cawley & Parmar, 2003), and (2) whether pre-algebra concept or reasoning were integrated in arithmetic learning of elementary mathematics to facilitate big idea conception and algebra readiness. The second research question was emerged from recent reform and regulations (NCTM, 2000) that call for algebra as a K-12 enterprise.

Method

Textbooks Selection

We selected four commonly adopted textbook series that were published in 1998 and in 2004. That is, the Scott–Foresman–Addison–Wesley (SFAW) Mathematics textbook series (Charles et al., 1998), the SFAW Mathematics textbook series (Charles, Crown, & Fennell, 2004), the Silver Burdett Ginn (SBG) mathematics textbook series (Fennell et al., 1998), and the Harcourt MATH textbook series (Maletsky et al., 2004). The rationale of selecting math textbook series that were published in two different time periods was to examine how mathematics curricula or textbooks responded to the new NCTM (2000) standards that endorse algebra readiness in K-12 math curriculum.

In addition, we included two reform-based textbooks, Everyday Mathematics (*EM*; Bell et al., 2004, developed by the University of Chicago School Mathematics Project) and Investigations in Number, Data, and Space (*Investigations*; TERC, 2008). Both programs are based on the work supported by the National Science Foundation. The rationale of selecting two reform-based textbooks is that many classrooms across the country are using reform-based curriculum and textbooks (for instance, according to EM's website, EM is currently being used in over 185,000 classrooms by almost 3,000,000 students). In reference to these two reform-based textbook series, we will call the above four commonly adopted textbook series as U.S. "traditional" textbook series hereafter.

We also selected a Chinese textbook as a comparison because numerous cross-cultural studies reported striking differences in U.S. and Chinese students' performance (e.g., Cai, 2000) and curriculum (e.g., Jiang, 1995; Li, 2000). In fact, cross-national studies (e.g., Becker, Sawada, & Shimizu, 1999; Cai, 1995, 2000, 2002; Silver, Leung, & Cai, 1995) have shown that Asian or Chinese students outperformed U.S. students in solving routine problems as well as certain types of nonroutine problems (Cai & Lester, 2005). Further, the difference in students' performance seems related to the differences found in the content presented by the textbooks (e.g., Li et al., 2008; Xin, 2007). For the Chinese textbooks, we selected the unified Mathematics textbook series (SESSCRC, 1995) for analysis because it was the only adopted curriculum (from 1991 to 2002) in the developed regions in China.

Table 1 presents the location (i.e., in which unit or chapter) and title of the analyzed lesson in each textbook series, respectively. As shown in Table 1, the title of the analyzed lesson is similar across five textbook series: It is all about "relating or connecting multiplication and division." Further, only one lesson in each textbook series addresses the connection between multiplication and division, which justifies the comparability of the selected lesson across different textbook series.

The analyzed U.S. "traditional" textbook was about 22 × 28 cm in size, and the analyzed lesson was about two pages (out of 500–750 pages including 12–30 chapters for the third grade). The analyzed U.S. reform-based

Table 1
Location of the Analyzed Lesson Across Seven Textbook Series

U.S. "Traditional" Textbook Series				U.S. Reform-Based Textbooks		Chinese Textbook
SFAW Math (1998)	SFAW Math (2004)	SBG Math (1998)	Harcourt Math (2004)	Everyday Mathematics (2004)	Investigations (2008)	SESSCRC Math (1995)
Grade 3	Grade 3	Grade 4	Grade 4	Grade 3 (Volume 1)	Grade 3	Grade 3 (Volume 2)
Chapter 7 Division Concepts and Facts	Chapter 7: Division Concepts and Facts	Chapter 3: Multiplication and Division Facts	Unit 3 Multiplication and Division Facts	Unit 4: Multiplication and Division	Unit 5: Equal Groups	
Section B: Using Multiplication Facts to Find Division Facts	Section B: Fact Strategies		Chapter 8: Practice Multiplication and Division Facts			
Lesson 4: Connecting Multiplication and Division (pp. 284–285)	Lesson 5: Relating Multiplication and Division (pp. 384–385)	Lesson 1: Relating Multiplication and Division Facts (p. 84–85)	Lesson 1: Relate Multiplication and Division (pp. 164–165)	Session 4.4: Division Ties to Multiplication (pp. 242–246)	Session 4.2: Multiply or Divide? (pp. 121–124)	Lesson 3: Relating Multiplication and Division, (pp. 32–44)

Note. SFAW = Scott–Foresman–Addison–Wesley MATH textbook series; SBG = Silver Burdett Ginn Mathematics textbook series; SESSCRC= Shanghai Elementary and Secondary School Curriculum Reform Committee.

textbooks were about 21 × 28 cm in size, and the analyzed lesson was about five pages. It should be noted that the two U.S. reform-based textbook series involve more than one book (e.g., *Investigations* has nine booklets; each booklet covers one unit that ranges from 120 to 237 pages). The practice problems of the EM lesson were found in *Math Journal* (additional three pages), and the practice problems of the *Investigations* lesson were found in *Student Activity Book* (additional three pages). In contrast, the analyzed Chinese textbook was about 12 × 18 cm in size, and the analyzed lesson was about 13 pages (out of 251 pages including 15 chapters for the third grade). Both the U.S. and the Chinese textbook series cover similar content focusing on addition/subtraction and multiplication/division. However, in contrast to the U.S. "traditional" textbooks, the Chinese textbook series did not include topics such as *understanding fractions*, *area*, *volume*, and *probability* in the third-grade mathematics.

Textbook Analysis Procedures

All of the analyzed textbooks (except for *Investigations*) divide the lesson into at least two parts: teaching the lesson (or learn about it) and practice (or check and then practice). As such, we conducted separate analysis for the teaching part of the lesson and the practice section of the lesson. *Investigations*, instead, divides the lesson into three parts: activities (solving story problems), discussion (multiply or divide), and follow-up (daily practice and homework). We did not analyze the mixed review (or mixed review and test prep) section as only some of the textbook series had this section in the lesson (Harcourt-2004, SFAW-1998, SFAW-2004), and most of the practice items included in the mixed review were dealing with the content students learned prior to the analyzed lesson.

Teaching Part Analysis. We conducted both quantitative and qualitative analyses of the selected lesson. For quantitative analysis, we counted the number of worked-out problems or guided practice problems in the teaching part of the lesson. For qualitative analysis, we compared how the lesson presented the connection between multiplication and division and the activities used to reinforce this big idea. We also analyzed problem schemata (or structure) of each word problem present in the lesson. The rationale of scrutinizing problem structure was to examine whether the lesson purposefully provides students with opportunities to solve problems with various situations to facilitate students' construction of multiplicative relations in multiplication and division problems. As recommended by the NCTM (2000) in its *standards*, students are presented with word problems and opportunities that encourage various types of reasoning. Providing opportunities to solve a variety of word problems encourages analytic thinking and reasoning.

Based on the problem schemata illustrated in Table 2 (under *problem schema feature*), the first two authors independently coded each problem to variations of each problem schema (e.g., rate times a quantity [R×Q], fair share [FS], and measurement division [MD] are three variations in EG problem structure). There was no disagreement between the two authors.

Practice Part Analysis. To capture the nature of the tasks present in the practice session of the lesson, we coded each problem along three dimensions. They are problem schema, response requirement, and algebra readiness features. Table 2 presents the three-dimensional model for problem coding with sample problems. First, we coded each word problem based on the *Problem Schemata* (see

Table 2
Three-Dimension Model for Problem Coding (With Sample Textbook Problems)

Problem Schema Feature (Word Problems)

Part-Part-Whole

Example: "What is the total number of cards Michael collected?" (Given the number of Football, Soccer, Baseball, and Basketball cards Michael collected in a Table format) (Harcourt-2004, p. 165)

Additive Compare

Example: "One camcorder costs 2,850 yuan, which is 3 times as much as one washing machine. (1) . . . (2) How much more does one camcorder cost than one washing machine?" (SESSCRC, 1995, p. 42)

Equal Group

Product unknown ($R \times Q$ type): The unit price of a box of Chinese checkers is 8 yuan. How much will it cost if you buy 7 boxes of Chinese checkers?

Number of units unknown (MD): The unit price of a box of Chinese checkers is 8 yuan. With a total of 56 yuan, how many boxes of Chinese checkers can you buy?

Unit rate unknown (fare share): With a total of 56 yuan, you can buy 7 boxes of Chinese checkers. How much does each box of Chinese checkers cost? (SESSCRC, 1995, p. 33)

Multiplicative Compare

Scalar unknown: There are 24 red balls and 8 blue balls. How many times as many red balls as blue balls are there?

Referent quantity unknown: There are 24 red balls. There are 3 times as many red balls as blue balls. How many blue balls are there?

Compared quantity unknown: There are 24 red balls. There are 3 times as many blue balls as red balls, how many blue balls are there? (SESSCRC, 1995, p. 41) .

Response Requirement

Numerical Answer Only

Example 1: "8 ÷ 2 = (SFAW-2004, p.385)

Example 2: "Henry has 2 oranges. He cuts each orange into 4 pieces. How many pieces of orange does he have?" (SFAW-1998, p. 285)

Explanation or Solution Required (e.g., open-ended questions)

Example 1: "Explain how you can use multiplication to solve a division problem. Give an example." (Harcourt-2004, p. 165)

Example 2: Solve each number story. Use counters, draw an array, or do whatever helps you find the answer. Fill in the diagrams and write number models:

There are a total of 36 pencils. Robert gives 3 pencils to each of his friends, how many friends will get 3 pencils each?

Friends	Pencils per friend	Total number of pencils

Answer: _____

Number Model: _____ (*EM*-2004, p. 245)

Table 2
Continued

Problem Schema Feature (Word Problems)
Special Requirement (e.g., create a problem) *Example:* "(1) The school bought 5 soccer balls with each cost 10 yuan. What would be the total cost? (2) Revise above problem to create two division word problems" (SESSCRC, 1995, p. 36).
Algebra Readiness Feature
Solve for the Unknown in Equation *Example:* Solve for the unknown x. $5 \times x = 105$ $\quad x \times 8 = 968$ $x \div 3 = 432$ $\quad 560 \div x = 4$ (SESSCRC, 1995, p. 38)
Concept of Inverse Operations *Example 1*: Based on the relationship between multiplication and division, fill in the brackets with numbers (without calculation) 1. $8 \times 9 = 72$ $\quad$ 2. $1608 \div 6 = 268$ $( ) \div 9 = 8$ $\quad 268 \times ( ) = 1608$ $72 \div ( ) = 9$ $\quad ( ) \div 268 = 6$ (SESSCRC, 1995, p. 34) *Example 2:* "What multiplication fact could you use to solve $10 \div 5$?" (SFAW-1998, p. 285)
Model Expression *Example 1*: "195 divided by x; the resulting quotient is 3" (SESSCRC, 1995, p. 39) *Example 2:* "The grandpa is 66 years old, which is 6 times Xiaohua's age. How old is Xiaohua? Solve it in two ways." (*Note*: One way, as modeled in the lesson, was to express the relation in an equation [i.e., $66 = 6 \times x$] and then solve for the unknown x in the equation) (SESSCRC, 1995, p. 40, *note added for clarification*)

Table 2). We then counted number of problems that were coded into each subtype.

Second, we looked at *Response Requirement*, which focuses on whether (1) only a numerical answer is required in the solution, (2) an explanation or other types of solutions are required, or (3) a special requirement is called for (e.g., create a problem). One of the NCTM process standards emphasizes reasoning in problem solving; that is, students not only provide a numerical answer to the problem but also need to explain why and/or how they get their answer.

Third, we examined the *Algebra Readiness Feature* of the problems presented in the practice section of the lesson. Specifically, we inspected opportunities for (a) understanding the concept of inverse operations between multiplication and division, (b) solving for the unknown quantity in an equation, and (c) model expression in algebraic equations.

The first and second authors independently coded each problem on three dimensions as defined above (i.e., problem schemata, response requirement, and algebra readiness feature). Discrepancies in coding between the two authors were resolved by coming to a consensual agreement. We counted the number of problems that were coded for each of the subcategories along three dimensions (see Table 2 for examples for each of the subcategories).

Results

Before reporting the results, it should be noted that the lesson in the Chinese textbook is divided into two subparts. The first part (Chinese-A), "Meaning and Relationships," defines and discusses the connection or inverse relationship between multiplication and division. The second part (Chinese-B), "solve for the unknown x," introduces equations. The lessons in the U.S. textbooks did not divide the lesson into two parts. As such, when reporting lesson analysis results for the teaching part and practice part, we provide information separately for each part of the Chinese lesson.

Teaching Part of the Lesson

Table 3 presents the analysis results on the teaching part of the lesson for one Chinese textbook series and four U.S. traditional textbook series. One distinctive feature of the

Table 3
Analyses of the Teaching Part of the Lesson for Chinese and U.S. "Traditional" Textbook Series

	Chinese-A	Chinese-B	Harcourt (2004)	SFAW (2004)	SFAW (1998)	SBG (1998)
Worked-out problems	3 EG word problems (R × Q, MD, and FS)	1 problem on "solve for the unknown x;" 1 model expression and solve for x; and 1 MC problem (referent unknown)	2 EG problems (R × Q and MD); Letter n was used to represent the product	1 EG problem (FS)	2 EG problems (R × Q and MD)	2 EG problems (R × Q and FS); Work with a partner and model with counters; represent given info in drawing and math sentence in one table.
How the lesson addresses connection	"A simple way to find out the sum of multiple equal-sized addends is named multiplication. In multiplication, the multiplicand and multiplier are also two factors of the product." "Given the product of two factors and one of the factors, the operation to find out the other factor is named division." "Therefore, division is an inverse operation of multiplication."	$8 \times 7 = 56$ factor × factor = product $56 \div 8 = 7$ $56 \div 7 = 8$ dividend ÷ divisor = quotient	Multiplication and division by the same number are opposite operations or invert operations. "One operation undoes the other."	How can a fact family help you divide? "Fact family show how multiplication and division are related."	"You can think about multiplication and fact families to divide."	(Students are asked to use counters and circles to model multiple equal groups within the story context) "Since each friend collected the same number of shells, a multiplication sentence can help you find the total"; "Since you are making equal groups, a division sentence can help you"
Models	$8 + 8 + 8 + 8 + 8 + 8 + 8 = 56$ $8 \times 7 = 56$ factor factor product Factor × Factor = Product Dividend ÷ Divisor = Quotient one factor = product ÷ another factor dividend = quotient × divisor; divisor = dividend ÷ quotient		(Harcourt-2004) $6 \times 3 = 18$, so $18 \div 3 = 6$ factor factor product dividend divisor quotient (SFAW-1998, SFAW-2004) factor × factor = product, dividend ÷ divisor = quotient		Number of friends × Number of shells for each = Total number of shells 3 × 4 = 12 Total number of shells ÷ Number of friends = Number of shells per friend 12 ÷ 3 = 4	
Other activities	Use 2 sets of fact family to illustrate one-to-one correspondence among the elements in various multiplication and division models, and induce all multiplication and division models; 2 guided practice items on fact family presented in the middle of the teaching part.	2 modeling items for *Solve for x* ($8 \times x = 288$, $x \div 4 = 502$); mapping numbers and operations to the model; 1 MC problem with the *referent* as the unknown (use both arithmetic and algebra approaches to solve)	Define fact family, present fact family	Use skip count (counting forward) to find the product or counting backward to find the quotient	Use concrete representations to show the problem-solving process; present fact family and use multiplication fact to solve division problems	Students were asked to use counters to model and make a table as in the worked-out problem (4 R × Q, 2 FS type). "Think and discuss: how did working with counters help you to understand how multiplication and division are related?"

Chinese lesson was that the worked-out problems were presented in a set of three problems with the same story context. The three problems in the set represent each of the three variations of the *Equal Group* (EG) problem type (i.e., *R×Q*, *MD*, and *FS*). As such, the lesson provided students with opportunities to solve EG problems with the unknown value in each of the three possible positions: (1) product (e.g., total number of items or whole), (2) multiplier or one of the factors (e.g., number of units/groups/sets), and (3) multiplicand or another factor (e.g., unit rate or number of items in each set/group). Division would be applied when solving for either of the two factors, whereas multiplication would be applied when solving for the product. Please refer to Table 2 under "Equal Group" for the three worked-out problems that represent three variations of the EG problem type presented with the same story context found in the Chinese lesson (SESSCRC, 1995).

As for how the lesson addresses the connection between multiplication and division, after reviewing the definition of multiplication, the Chinese lesson presents the relationship between multiplication and division within the context of a generalizable model, "factor × factor = product." One-to-one correspondence for each of the three elements in the multiplication model (factor × factor = product) and division model (dividend ÷ divisor = quotient) was visually displayed using connecting arrows (see Table 3, second column, third row). Furthermore, the Chinese lesson presented all variations of the multiplication and division models (factor × factor = product, one factor = product ÷ another factor; dividend ÷ divisor = quotient; dividend = quotient × divisor, divisor = dividend ÷ quotient) following corresponding modeling problems.

In contrast, worked-out example problems presented in the U.S. textbooks are either a single EG problem type (i.e., FS) as in the case of SFAW (Charles et al., 2004), or a set of two problems (either a combination of R×Q and MD or a combination of R×Q and FS) as in the cases of the other three U.S. textbook series (i.e., Harcourt-2004, SFAW-1998, SBG-1998) as well as the two reform-based textbooks (Bell et al., 2004; TERC, 2008). None of the U.S. lessons analyzed in this study presented a set of three problems that exhaust all variations of the EG problem type as observed in the Chinese lesson. None of the U.S. lessons present various multiplicative compare (MC) problem situations.

As for how the lesson presented, the connection or relations between multiplication and division, most of the U.S. traditional textbook lessons emphasized a fact family such as "a fact family shows how multiplication and division are related" (SFAW-2004, p. 384). In contrast to the Chinese lesson, the analyzed U.S. lessons did not provide a visual display of one-to-one correspondence for each of the three elements between the multiplication and the division models. In addition, mathematical expressions of all variations of the multiplication and division models were not exhausted. Some of the U.S. lessons (SFAW-1998, SFAW-2004) presented the two primary models only (i.e., factor × factor = product and dividend ÷ divisor = quotient). One distinctive feature found in most of the U.S. lessons (e.g., SFAW-1998, SFAW-2004, Harcourt-2004) was an emphasis on an explanation about how multiplication can be used to find the answer to a division problem (e.g., "What multiplication fact could you use to solve 10 ÷ 5?") (SFAW-1998, p. 285).

The two reform-based textbooks are somewhat different (see Table 4 for qualitative and quantitative analyses of the teaching part of the lesson for the two U.S. reform-based textbook series). For instance, the lesson in *Investigations* focuses on multiple EGs when explaining the concept of multiplication, and distributive reasoning when explaining the concept of division (see Table 4, second column, second row). In contrast, the lesson in *EM* presents a diagram in the form of a 2 × 3 table (see the diagram presented in Table 4, second row, third column) to address the relationship between multiplication and division. However, in the "diagram," the relationship among the three elements is not specified (i.e., the factor × factor = product).

On the other hand, the second half of the Chinese lesson, "solve for the unknown x," is unique. This part of the lesson is designed to show students through modeling and guided practice how to solve for an unknown x in various equations with the x placed in all possible positions in the equation (e.g., $8 \times x = 288$; $x \div 4 = 502$; $756 \div x = 3$). In each of the three modeling problems, the lesson taught students to express the mathematical relations given in the problem in an equation with letter x to represent the unknown and then solve for x in the equation. Following this model expression instruction, the lesson presents a real-world problem (an MC problem type) and shows how to use model expression to solve an MC problem with the *referent* quantity as the unknown (i.e.: There are 72 "Well-Behaved Children" magazine books, which is nine times as many as "Juvenile Science" magazine books. How many "Juvenile Science" magazine books are there?). Further, this model expression or algebraic approach ($x \times 9 = 72$, $x = 72 \div 9$, $x = 8$) was compared with the arithmetic approach ($72 \div 9 = 8$) in solving the problem.

This systematic pre-algebra instruction, as observed in the second half of the Chinese lesson, was absent in most

Table 4
Analyses of the Teaching Part of the Lesson for U.S. Reformed-Based Textbook Series

—	Investigations	Everyday Math
Worked-out problems	3 EG problems (2 R × Q, 1 MD) No worked-out problems. However, the lesson asked students to **discuss** 3 EG problems (2 R × Q, 1 MD) (discuss what do you know and what are you trying to find out?) Also students are encouraged to act out each problem, using cubes or drawings	2 EG problems (1 FS, 1 MD) Students are taught to use array pictures, number sentence, and diagrams to solve 1 EG problem (FS). Students are asked to solve 1 EG problem (MD) by using the diagram and find out the missing number in the diagram
How the lesson addresses the connection between multiplication and division	This problem (refer to the R × Q problem) "identifies the number of groups and the number of items that are in each group. Because they need to find how many are there altogether, this is a multiplication problem." (p. TERC, p.122) Through acting out division problems, students will recognize division situation "starting with an amount that get divided into equal groups" (TERC, p.122) Students discuss about using the inverse relationship between multiplication (5 x 4 = 20) and division (20÷4 = 5) to solve problems.	The result of the division is called the quotient. The dividend is the total before sharing. The divisor is the number of equal parts, or the number in each equal part. The diagram (see below diagram from page 243 of the book) serves to reinforce the inverse relationship between the two operations. Children | Pennies per child | Total number of pennies 4 | ? | 28
Other modeling or activities	Discuss the difference between an MD division and an R × Q multiplication problem. Listen for students to identify the MD problem as a division problem because we are told the total and are asked to find how many equal bags can be made. The R × Q problem is a multiplication problem as we are told how many packs were bought and are asked to find how many cups altogether.	1. Pose additional problems, as necessary. For each problem, ask students to fill in a multiplication/division diagram and write a number model (e.g., 3 × 12 = ?, 36 ÷ 3 = ?). 2. Students play division arrays.

analyzed U.S. lessons except the lesson in the Harcourt-2004. The lesson in the Harcourt-2004 introduces a letter to represent an unknown in the equation; however, the letter is only used to replace the unknown as the ending product or answer to an arithmetic math sentence ($6 \times 3 = n$, $6 \times 3 = 18$, and $18 = n$). Nevertheless, the lesson was titled "Algebra: Relate Multiplication and Division."

Practice Part of the Lesson

Table 5 presents descriptive analyses of problems presented in the practice part of the lesson for the selected Chinese and U.S. traditional and reform-based textbook series along the dimensions of problem schemata, response requirement, and algebra readiness.

Analysis of Problem Schemata. When the dimension *problem schemata* was examined for all word problems

Table 5
Analyses (# of items) of Practice Problems Along Three Dimensions for the Chinese and U.S. Textbook Series

—	Chinese-A	Chinese-B	Chinese (A + B)	Harcourt (2004)	SFAW (2004)	SFAW (1998)	SBG (1998)	Investigations	EM
Problem schema feature									
Part-part-whole	0	0	0	2	1	0	0		
Additive compare	0	1	1	0	0	0	0		
Equal group	2	0	2	1	1	1	0	7	8
Multiplicative compare	0	14	14	0	0	0	0	0	0
Algebra readiness									
Concept of inverse operations	23	0	23	6	11	15	1	0	0
Solve for the unknown in equation	0	29	29	16	0	0	0	0	0
Model Expression	0	8	8	0	0	0	0	0	0
Response requirement									
Numerical answer only	21	61	82	19	11	13	0	7	0
Explanation/solution required	0	5	5	6	3	3	3	0	8
Special requirement (e.g., create a problem)	2	0	2	0	0	1	0	0	0
Total # of items	23	66	89	25	14	17	3	7	8

present in the practice section of the lesson, it was found that the first part of the Chinese lesson (Chinese-A) presented two EG problems in the practice sections. It must be noted that although there were only two EG problems (one R×Q problem and one FS problem), students were asked to revise the R×Q problem into two division problems (i.e., MD and FS) and to revise the FS problem into a multiplication problem (i.e., R×Q). As such, students were provided with opportunities to solve two sets of EG problems with each of the three elements (e.g., unit rate, number of units, and product) in the EG problem schemata as the unknown. This is consistent with the teaching part of the lesson where three EG problems (i.e., R×Q, MD, and FS presented with a same story context) are modeled.

Most of the U.S. lessons presented only one form of the EG problem type. The problem type presented in both the Harcourt-2004 lesson and in the SFAW-1998 lesson was the FS problem type. The one problem present in the SFAW-2004 was the MD type. Interestingly, the lesson in the SBG (Fennell et al., 1998) does not have any word problems that require a numerical answer in the practice section of the lesson.

In contrast, the two reform-based textbook lessons present all three variations of EG problems in the practice

sections of the lesson. Specifically, in the *Investigations* lesson's practice section, there are three FS and three MD problems, and one R×Q problem. However, recall that in the teaching part of this lesson, only two of the three variations of the EG problem type (i.e., R×Q and MD) were presented as worked-out modeling problems. In the lesson in EM, there were three FS, three MD, and one R×Q problems in the practice section of the lesson. However, in the teaching part of this lesson, only two of the three EG types were presented as worked-out problems (i.e., FS and MD).

In addition, the second part of the Chinese lesson (Chinese-B) presented 14 MC problems for students to solve following a worked-out MC problem solving in the teaching part. In contrast, this problem type was completely absent across all analyzed U.S. lessons. Among the 14 MC problems in the analyzed Chinese lesson, some of them were presented in a set with an exact same contextual story (see a set of three *MC* sample problems provided in Table 2 under "problem schema feature" from SESSCRC [1995, p. 41]). As in the teaching part of the Chinese lesson, the problem set provides students with opportunities to solve for each of the three elements in the MC problem schema (i.e., compared quantity = scalar × referent quantity). The first problem (see Table 2, MC under "problem schema feature") asks for the *scalar*; the second problem asks for the *referent* quantity; and the third one asks for the *compared* quantity. Division was called upon when solving for the first two problems, whereas multiplication was needed to solve for the third problem.

In addition to EG and MC problem types, there were few *part-part-whole* and *Additive Compare* problems present in the practice sections of the lesson across analyzed Chinese and U.S. lessons. Presumably, these problems were presented for students to review addition and subtraction they learned prior to multiplication and division.

Analysis of Response Requirement. Along the dimension of *response requirement*, it seems that the ratio of problems requiring explanations or solutions versus problems requiring a numerical answer only is greater in the analyzed U.S. traditional textbook lessons (ranged from 3:0 to 3:11) when compared with the Chinese lesson (5:82). In fact, the five problems that were coded as "explanation or solution required" in the Chinese lesson were all nonroutine problems in a section called "Brain Teasers." No items in the Chinese lesson required an explanation about the inverse operation between multiplication and division. In contrast, most analyzed U.S. lessons required students to write the fact family and explain how multiplication can be used to solve a division problem. As for the special requirement feature, the Chinese lesson provided students with opportunities to create two variations of the EG problem when provided with one form of EG problem. Most of the U.S. lessons did not provide opportunities for students to create a problem except the lesson in SFAW-1998. In contrast to the Chinese lesson, the SFAW-1998 lesson asked students to create a division problem with no specific guideline.

Interestingly, the two reform-based textbook lessons ranged at the two extremes. The *Investigations* lesson did not ask students to provide explanations about their answers to any of the word problems solved. In contrast, in the EM lesson, students were asked to show their solution using the diagram (see Table 4, second row, third column) they learned. Specifically, students were asked to "solve each number story. Use counters, draw an array, or do whatever helps you find the answer. Fill in the diagrams and write number models" (i.e., number sentence, for instance: $3 \times 12 = ?$ or $36 \div 8 = ?$) (Bell et al., 2004, p. 246).

Analysis of Algebra Readiness. One of the most important differences between the U.S. lessons and the Chinese lesson is related to the *algebra readiness* feature. The Chinese lesson devoted a separate section to introduce the concept of equations and solving for an unknown x in the equation (e.g., $x \div 5 = 955$). In contrast, most analyzed U.S. lessons provided practice opportunities for students to fill in the missing number in a math sentence (e.g., $2 \times (\ ) = 8$, $8 \div 2 = (\ )$; SFAW-2004, p. 385). The exception was the lesson in the Harcourt-2004, where 16 items in the practice section required students to "find the value of the variable in an equation" (e.g., $18 \div n = 2$). Interestingly, we found no such problems (a letter or "variable" present in a position other than the ending product) modeled in the teaching part of the lesson (Harcourt-2004). Further, we found that the numerals involved in these problems were basically one- or two-digit numbers. As such, the unknown letter in the equation could be easily solved with mental math using the knowledge of fact families.

Another unique finding is that there are eight items in the Chinese lesson requiring students to express mathematical relations in an equation with letter x to represent the unknown and then to solve for x (e.g., "195 divided by x; the resulting quotient is 3") (SESSCRC, 1995, p. 39). These problems were coded as *model expression* because students have to represent the problem or mathematical relations in an equation and then to solve for the unknown x in the equation. This type of *model expression* problems was absent across all analyzed U.S. lessons.

Beyond the three dimensions, one interesting observation is that the numerals appear in the problems in the

Chinese lesson (e.g., ( ) ÷ 9 = 205, 1,688 ÷ x = 8) were much bigger than the numerals appearing in the U.S. lessons (e.g., 5 × ( ) = 35, b ÷ 4 = 8). To solve for problems with small numbers present in the U.S. lessons, students may only need to apply the knowledge of fact family with mental math. In fact, using mental math of fact family for solution is what is emphasized in most of the U.S. lessons. However, to solve the problems present in the Chinese lesson, students would be expected to either use algorithms taught in the lesson (e.g., divisor = dividend ÷ quotient) or use model expression in the form of algebraic equation to solve for the variable x in problems such as "1,688 ÷ x = 8" rather than mental math. Another interesting finding is that the Chinese lesson presents a considerable amount of problems in purely mathematical context ("8 times a number is 768. What is the value of this number?") (SESSCRC, 1995, p. 38), especially in the beginning part of the lesson when concepts/algorithm are newly introduced and in the "*solve for an unknown x*" part of the lesson. These pure mathematical contextual word problems were not seen in any of the analyzed U.S. lessons.

Discussion

The discussion and conclusion of this study should be interpreted with caution. Our study is limited in that only four commonly adopted U.S. textbook series and two NSF-supported reform-based textbook series were evaluated. The Chinese textbook series represents the unified curricula adopted in the developed regions in China. In addition, we examined only one lesson on teaching the connection or relation between multiplication and division. Further, the findings of this study did not take into consideration other materials that teachers might use to supplement the textbooks. Finally, textbooks only represent an intended curriculum. The enacted curriculum (i.e., what is actually happening in the classroom) was not examined and was beyond the scope of this study. Providing these limitations, we summarize the findings of this study as follows.

Analyses of both the teaching and practice parts of the lesson indicate that the Chinese lesson provides many more worked-out problems and practice opportunities when compared with the analyzed U.S. lessons. It should be noted that although the volume of the U.S. textbooks is generally much larger than the Chinese textbook, it appears that the Chinese textbook is more concentrated covering fewer topics. Fundamental concepts or big ideas (such as the lesson addressing the connection between multiplication and division) were given more attention or page spaces than some other less central topics (e.g., simple bar graph, three pages). In contrast, the U.S. "traditional" textbooks tend to give each lesson equal spaces or emphasis. On the other hand, the spiral program features of the U.S. textbooks might have contributed to the larger volume of the book; the textbook in each grade has to cover many topics including both a review of old topics and presenting new contents. Consequently, it falls short in providing in-depth coverage of any topic with thorough explanations and a range of worked-out examples in a single textbook, when compared with textbooks used in other countries (Mayer et al., 1995).

Differences Between the U.S. and the Chinese Lessons in Facilitating Conceptual Understanding

One of the most significant findings of this study is a prominent distinction between the U.S. and the Chinese lessons in mathematical feature of the problems present in the lesson. Specifically, the Chinese lesson presents purposefully constructed problem sets in the teaching and practice sections of the lesson. Students were provided with opportunities to solve all variations of a problem type (i.e., three variations of the *EG* problem type and three variations of the *MC* problem type) to facilitate problem schema acquisition.

This textbook design feature found in the Chinese lesson reflected its intent to explicitly teach big ideas that facilitate efficient and broad acquisition of knowledge, specifically the multiplicative problem schema (factor × factor = product) that depicts the inverse relationship between multiplication and division. A problem schema is a general description of a group of problems that share a common underlying structure (e.g., *EG*s) requiring similar solutions (Chen, 1999; Gick & Holyoak, 1983). Schemata are the appropriate mechanism for the problem solver to "capture both the patterns of relationships as well as their linkages to operations" (Marshall, 1995, p. 67). Schema acquisition promotes both conceptual understanding and procedure knowledge in problem solving.

In contrast, the findings of this study indicate that lessons in U.S. "traditional" textbook series emphasize the use of manipulatives such as counters (or drawing a picture) to facilitate conceptual understanding of the relation between multiplication and division (SFAW-1998, SFAW-2004, SBG-1998). In addition, most of the U.S. traditional textbook series' lessons (except for SBG-1998; the lesson in the SBG-1998 asks a more open question: "Tell how multiplication and division are related," p. 85) ask students to explain why multiplication or specifically what multiplication fact can be used to find out the solution to a division problem (e.g., 28 ÷ 4). That is, most of the U.S. lessons in the "traditional" textbook series only

emphasize how to use a multiplication fact family to solve a division problem. Direct applications of division models (e.g., one factor = product ÷ another factor) for solving division problems are not emphasized. Although it is important for students to understand how fact families can be used to solve simple division problems, it is equally important for students to learn to use division models (deduced from the general "factor × factor = product" model) to directly solve a division problem. Emphasis solely on using multiplication facts to solve division problems might hinder students' ability in solving a division problem effectively and efficiently (especially when the problem involves big numbers) and result in limited conceptual understanding of the inverse relationship between multiplication and division.

Compared with the U.S. traditional math textbook series, the two reform-based textbook lessons seem to teach more explicitly about the meaning of the multiplication and division in the context of EGs. Both *Investigations* and *EM* used a table to list three elements in the EG problem schema: number of groups, number in each group, and product. However, the relationship among the three components is not explicitly presented (i.e., number in each group × number of groups = product). In contrast to the Chinese lesson, the multiplicative comparison problem situations are completely excluded in all analyzed U.S. textbook lessons that address the connection between multiplication and division.

In summary, the Chinese lesson's penetrating analysis or explanation of the topic is reflected in its deliberately constructed examples and wide range of problems (pertaining to problem types and difficulty levels) present in the teaching and practice sections of the lesson. None of the analyzed U.S. lessons are comparable with the Chinese lesson with respect to the breadth and depth in teaching the topic. It seems that the Chinese lesson promotes conceptual understanding through an emphasis on problem schema acquisition, whereas most of the U.S. lessons resort to manipulative or concrete representation for teaching conceptual understanding. Compared with the more traditional U.S. textbook series, it seems that the two reform-based textbook lessons elaborate more explicitly the three elements in the EG problem schema. However, it was restricted to the *EG*s context only.

Differences in Algebra Readiness Instruction

The NCTM (2000) standards and the nationwide mathematics reform call for algebra readiness in elementary mathematical learning. The lessons from the two U.S. textbook series that were published in 1998 did not introduce any symbols to represent an unknown or variable in the form of equations. Concrete representations such as counters were used to represent the problem and to facilitate conceptual understanding. We found no significant differences between the SFAW-1998 and SFAW-2004 in lesson design or construction. Although the SFAW-2004 used "algebra" as the title for a list of key ideas to be learned in the lesson, the lesson did not introduce any symbolic representation for an unknown in equations.

The Harcourt-2004 is somewhat different. The lesson was titled "Algebra: Relating Multiplication and Division." However, in the teaching part of the lesson, letter "*n*" was *only* used to represent the unknown answer of a math sentence; it was not present in any other positions of the equation. Although the Harcourt-2004 lesson seemed to introduce a "variable" *n* in equations, students did not have to use algorithm or pre-algebra knowledge to solve for the "variable." Rather, they were expected to use fact families to find the value of the "variable" in equations involving simple one- or two-digit numbers. Interestingly, the two reform-based lessons did not include any algebra readiness components in this lesson.

In contrast, the second half of the Chinese lesson, "solve for the unknown *x*," systematically introduces the pre-algebra concept through teaching students to solve for an unknown *x* in various equations and use algebra model expressions to solve arithmetic word problems. One distinctive feature of the Chinese lesson is its deliberate placement of the "unknown" *x* in all possible positions across various multiplication and division equation models; and the numerals involved in the equation are big enough so that students are not able to rely on mental math to figure out the answer for *x*. Again, this emphasis on problem schemata acquisition, unique to the Chinese lesson only, is expected to facilitate the grasp of the big idea and high-level conceptual understanding and reasoning.

Another observation was the purely mathematical context (skeleton) problems present in the analyzed Chinese lesson. It may be the case that these problems, compared with rich context real-world problems, eliminate distractions so that students clearly see mathematical elements and relations without the distraction of the rich contexts. The presentation of the "skeleton" problems makes the mathematics structure explicit.

Conclusion and Implications

As part of the mathematics reform and standard-based reform movements, the NCTM (2000) developed the Principles and Standards for School Mathematics. The focus of

the NCTM standards is on conceptual understanding. According to Hiebert and Lefevre (1986), conceptual knowledge "is achieved by the construction of relations between pieces of information" (p. 4). In the United States, for instance, educators have been emphasizing the use of concrete manipulations to facilitate conceptual understanding and may treat "conceptual understanding as separate from the use of mathematical notations" (Sherin, 2001, p. 482).

Concrete manipulation with small numbers may be essential when a concept is introduced in the beginning stage of the learning; however, explicit instruction, with carefully selected examples that represent exhaustive range of situations, is important for students to grasp problem schemata of multiplicative problem situations for instance. This represents a higher order of conceptual understanding, which typically involves symbolic or algebraic representation of mathematical relations in an equation.

With reform-based instruction, students are expected to construct the knowledge themselves with guidance. One of the rationales is that it is not possible to inject the knowledge to one's head. There is a fear to explicitly present students with the concept/theorems at the symbolic level in particular. One of the striking differences between the U.S. and the Chinese lessons in addressing the inverse relations between multiplication and division is the explicit teaching of multiplicative reasoning through schema acquisition. With sets of an exhaustive range of examples, the inverse relationship between the multiplication and division is clearly defined not only at a concrete level (multiple context stories or word problems) but also at a symbolic level (model expressions that depict the relationship between elements in the model; see Table 3, third row).

Some of the U.S. textbook series (Harcourt-2004) intended to integrate algebra in elementary mathematics learning. However, simply replacing the answer (for the unknown) with a letter "variable" may represent a superficial decoration of "algebra" in elementary mathematics learning. Symbolic representation and algebraic thinking would not be facilitated and infused. The findings of this study, as part of informative cross-cultural comparison research, may provide textbook/curriculum designer with insights and models in integrating algebraic reasoning into elementary arithmetic mathematics learning.

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Authors' Notes

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Looking Back at the Sputnik Era and Its Impact on Science Education

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In celebration of the recent golden anniversary of the launching of the Soviet satellite, Sputnik I, this paper takes an historical perspectives approach to examine the social, political, and educational climate in the United States leading up to the launch. Ramifications to science education are discussed, and implications are made for the relevance of this event to science education today.

Two years and seven months after the initiation of the U.S. satellite program, Soviet Russia launched a rocket north of the Caspian Sea carrying the now famous *Sputnik I* satellite. U.S. scientists were aware that Soviet Russia was planning on putting an artificial satellite into orbit (TIME, 1957); however, secrecy surrounding the timing and the location of the launch of the satellite served to intensify the Cold War and America's deepening distrust of Soviet Russia (Hartman, 1955). Launching of the Soviet Russian's satellite had been planned and previously announced as part of the International Geophysical Year, an 18-month multinational scientific study of the Earth, its crust, atmosphere, and space surrounding it. It was widely believed in the scientific community that the satellite's intended purpose was to take samples of the atmosphere (Ubell, 1957) and pictures of the Sun's corona (Berry, 1957; Ubell, 1957). On the day following its launch, the polished aluminum sphere with a mass of 83.6 kg and a diameter of 58 cm bearing four antennae was successfully circling the earth every 92 minutes at a velocity of 8,000 meters per second. For the first two days after the launch, Americans could see Sputnik, through a telescope or binoculars in the light of the rising or setting sun (Wald, 1957). Although its "beep" was broadcast for 21 days, by October 6, 1957 only sensitive receivers and home radios equipped to receive short wavelengths could prove Sputnik's presence. Soviet Russia credited its satellite success to communism and crowned Tsiolkovsky as the king of space fight (Cutler, 1957). The American people were both bewildered and frightened by the orbiting metal sphere known as the Red Moon. They were wondering if it could fall out of space, how fast it was going, what held it up, if it had military value, and if they could hear the radio signals from it on their own radios. More importantly, the launch deeply shook America's confidence in her technological superiority to Soviet Russia and left government officials, politicians, scientists, and educators scrambling to find ways to close the gap.

Education in general and science education in particular seems to be in a constant state of reform. New trends last about 15–20 years before being replaced by a new set of philosophies, goals, or teaching strategies. Sometimes, new reforms vary slightly from the old and seem to be part of a natural evolution; at other times, the changes are more radical. Arguably, one of the most radical shifts in the history of science education in the United States came on the heels of the launch of the Soviet satellite *Sputnik* on October 4, 1957.

The launching of Sputnik was a trumpet call to the U.S. educational system. Even if the public did not know much about rocketry, satellites, or space, they did understand a perceived blow to national pride. Until that time, the United States stood at the forefront of medical research, automobile design and manufacture, and electronics. The launch of Sputnik changed all that. The United States was suddenly seen as having fallen behind, and the focus was now not on catching up but on surpassing her adversary. To do this, schools would have to improve their science curricula from the societal aspect of the progressive era to much more rigorous courses of study that winning the space race would demand. Toward this end, Congress passed the National Defense Education Act (NEDA) in 1958, which encouraged the development of high-quality science and mathematics programs to encourage scientific careers.

The State of Science Education Before Sputnik

World War II (WWII) had a tremendous and far-reaching impact on the American educational system. Vocational and applied aspects of education that had been gaining strength since their inception came into their own during the early 20th century, as the war effort required an increase in the production of both industrial and agricultural products on a scale never before seen in this nation's history. People seeking to fill these positions in civilian life as well as those entering the military had to be trained in these fields. The entire educational system was in need of

improvement as revealed by recruits' lack of basic knowledge and skills in the areas of literacy, mathematical reasoning, and general health (DeBoer, 1991). Personnel shortages in important scientific, industrial, and technical fields demonstrated that schools were not meeting the educational needs of an increasingly technical workforce. Science, mathematics, and technology had been critical for military success during WWII, and this trend continued through the postwar years as competition with Soviet Russia for technological and military supremacy increased. One major outcome of WWII was the United States' fortified commitment to the principles of democracy, which required a strengthening of "our efforts at universal education and the general education of all American youth" (DeBoer, 1991, p. 129).

To meet the military's demand for technical personnel during the war years, many science faculty members had been siphoned from colleges and universities to work on military projects, to train military personnel, and/or to fill better paying positions in industry or in government. Due to the government's position of denying deferments to college students majoring in the sciences, fewer science majors were available for postwar responsibilities. The combined loss of science faculty and science majors resulted in a reduction in the numbers of scientists and faculty available for the returning soldiers who utilized the Servicemen's Readjustment Act of 1944, commonly referred to as the GI Bill, to obtain a college education. As a result, university faculty had to deal with overcrowded classrooms, poor facilities, and little time to devote to their scientific research (DeBoer, 1991).

In an attempt to address these issues, President Harry Truman authorized the establishment of the President's Scientific Research Board on October 17, 1946 by Executive Order 9791 (1947). The purpose of the Board was to study the nation's science programs and to make recommendations for improvement. In light of the fact that other nations, particularly the Soviet Russia, were investing heavily in scientific research and technology, emphasis needed to be placed on developing science research and on teaching in institutions of higher education. To assist in addressing these inadequacies and in encouraging research, the Board recommended higher salaries for college science faculty, increased funding for scientific research, and the establishment of the National Science Foundation (NSF) with the purpose of coordinating science research grants for universities and colleges (DeBoer, 1991; Truman, 1947).

Recognizing the importance of a strong foundation in science at the K-12 level, the Research Board sought ways to encourage elementary students' interest in the sciences that could carry through to higher education. A successful program of scientific research began in the elementary and secondary classrooms to study the effectiveness of science education at the K-12 level not only for those students who were interested in science but also for those students not planning to pursue further education in a science field. In this way, the Board attempted to include a wider nonscientific community in supporting and in understanding science, beginning with the nation's youth.

Cultural Events at the Time of Sputnik

The mid-1950s, years leading up to the launch of Sputnik, was a period of social and cultural tensions for the United States. A review of popular magazines including *Time*, *Newsweek*, *Life*, *Look*, *Saturday Evening Post*, and others document the launch of Sputnik occurred in changing times. Uppermost in the minds of the American people at the time were the events in the news and entertainment. Internationally, the United States had recently emerged from the Korean War (1950–1953), a conflict that had focused the nation's attention on the threat of communism and the growing significance of the small Southeast Asian country of Viet Nam. Domestically, many issues were on the minds of Americans. Social inequities were becoming apparent. The plight of migrant workers and the rural poor, especially in Appalachia, was gaining attention. Racial discrimination, epitomized by segregation laws, was under fire, leading to the rise of what would become known as the civil rights movement. In *Brown v. Board of Education* (1954), the U.S. Supreme Court ruled that segregation was unconstitutional. In 1957, President Eisenhower ordered the desegregation of Little Rock Central High School and enforced by federal troops. In 1956, a young Martin Luther King Jr. led the bus boycott in Montgomery, Alabama. The year before, Rosa Parks had refused to move to the back of the bus she was riding. Evangelist Billy Graham, in a national welling of religious atmosphere, was attracting the attention and gaining support of millions worldwide. Other issues that were vying for the nation's attention were the environment, the changing role of women in society, labor unions, a major influenza epidemic, and nuclear testing. The postwar American economy was prosperous; with salaries on the rise, American consumers sought all manner of commercial goods, leading an escalating variety of new products, a host of new marketing ideas, development of the suburbs, and the shopping mall. In the fall of 1957, sports fans were focusing on the World's Series involving Milwaukee and the New York Yankees. In other areas of

entertainment, actors such as Marilyn Monroe, James Dean, and Marlon Brando signaled a change in the social climate of the nation. In music, Elvis Presley was thrilling teens and shocking adults with his version of rock and roll, accompanied by gyrating dance moves. Television was quickly becoming the dominant media, spreading the message of consumer abundance and introducing entertainment into American living rooms (Boyer, 2001; Dickson, 2001). Coincidentally, *Leave It to Beaver* also premiered on October 4, 1957. Individuals desiring more information on how Sputnik influenced a rural mining community could read Homer Hickam's (2000) biography *Rocket Boys* or watch the movie *October Sky* (Cramer & Sternberg, 1999). The Sputnik impact and science fair competition documents life of the late 1950s.

Communism was perceived as a threat for several reasons: (1) It was a different system than democracy. (2) Other communist countries had the atomic or hydrogen bombs. And (3) the United States had never lost a race involving technology and perceived that Soviet Russia was serious competition. This last reason was perhaps the most psychologically powerful. After all, it was the United States who could boast the first powered flight, the first mass-produced automobile, the vaccine for polio, and numerous other inventions and "firsts" (Dickson, 2001). As a nation, Americans had grown accustomed to being at the forefront of technological advancements and found it difficult to accept that a country with political and economic philosophies that were so different could threaten their superiority in areas of science and technology.

Militarily, Sputnik was of great concern to the United States because it clearly demonstrated to the world Soviet Russia's ability to develop and launch an intercontinental ballistic missile (ICBM), a feat that put the United States within striking distance of a weapon carrying a potential nuclear warhead. While the United States was still struggling to launch its Vanguard rocket (Bracker, 1957), the Soviets had succeeded, making visible what was to become known as the "missile gap."

The United States Reacts to Sputnik

In launching Sputnik, the Soviets did not pass up the opportunity to extol the virtues of the "new socialist society" that could turn the dreams of mankind into reality (Jorden, 1957) and indicated plans to launch more and larger artificial satellites in the near future. Soviet Russia's military officials publicly stated that the satellites would have no practical military applications in the near future, including worldwide aerial inspection of military forces, nor could they be used to drop hydrogen bombs on the Earth. Privately, however, was another matter. Soviet Russia refused to share information regarding the progress of their program, leading to speculation regarding the real intent behind the missile program (National Security Council, 1957).

The 1950s and early 1960s were a period of social change in the United States. Abroad, attention was turned from Korea and the military and political conflict between the opposing ideologies of democracy and communism. Distrust between Soviet Russia and the United States had resulted in the Cold War. Political tensions in Southeast Asia and Viet Nam were on the rise. Domestically, *Brown v. Board of Education* brought racial inequality to the educational forefront. The civil rights movement and events in Little Rock, Arkansas dominated the news. Women were starting to raise their voices for greater equality. The environmental movement was gaining attention on many fronts after the publication of Rachel Carson's (1962) *Silent Spring*. Increasing attention was focused on issues related to poverty. Rock and roll was redefining the music scene.

With so many other issues occupying the attention of the American people, they were uncertain of how to react to the launching of the satellite. While some newspapers, like the *New York Times*, devoted much of the front page to the Sputnik story, most media buried the event on back pages and ends of newscasts. At that time, most newspapers focused on the integration of Central High School in Little Rock, the World Series, or Jimmy Hoffa and the Teamsters Union. Most people attending the International Affairs Seminars of Washington (1958) reported that they had never heard of an "earth satellite" and knew even less about rockets or space. They reported that people were not generally impressed by the "beeps" broadcast from the orbiting satellite and were unaware of the military implications of satellite technology.

U.S. Government Reaction

The reaction of the U.S. government to the launching of Sputnik could be separated according to the branch (executive, legislative, military, etc.) examined. President Dwight D. Eisenhower at the time was preoccupied with civil rights events unfolding in Little Rock, Arkansas. Lyndon B. Johnson, then senate majority leader, reported feeling uneasy and apprehensive, and immediately called for support from both political parties to investigate the use of missiles and space. Ironically, John F. Kennedy, then senator from Massachusetts, showed little public interest in Sputnik, calling rockets a "waste of money" and their use in space "frivolous" (Dickson, 2001, p. 19).

Reactions were mixed among the President's National Security Council. In the meeting of October 10, 1957, less than a week after Sputnik was launched, reactions ran the gamut from paranoia to malaise. On the one hand, there were those who were quick to accuse Soviet Russia of using their satellite to send out encoded messages, spy on U.S. military installations, or even had a plot to explode a hydrogen bomb on the lunar surface during the height of an eclipse (Sullivan, 1957). Those on the other end of the spectrum expressed the thoughts that the launching of the satellite was little more than communist propaganda and would not amount to much (National Security Council, 1957).

Regardless of the public reaction by government officials, one thing was deeply disturbing: the Soviet Russians had dealt a blow to United States' image and prestige. Privately, U.S. scientists agreed that the launch proved that the Soviets had perfected their design for ICBMs, which posed a real threat to the United States, as they were capable of carrying atomic warheads for long distances. Meanwhile, progress in launching the Vanguard missile was slow, plagued with malfunctions and disappointment. The United States could not seem to get one of their missiles off the launch pad (Bracker, 1957). Psychological and political pressure to launch a rocket greatly increased after the launches of Sputnik I on October 4th and quickly followed by Sputnik II a month later on November 3, 1957.

Reaction of the Science Community

Scientists, on the other hand, were keenly aware of the implications of the launch. Alan Shepherd commented that this event would affect him directly and quickly. John Glenn, who knew that space flight would become the "yardstick for measuring military superiority," echoed the same sentiment (Dickson, 2001, p. 19). Scientists and science educators alike were excited at the prospect that school curriculums would now have to turn from their progressive science to a much more rigorous curriculum to produce the kinds of students who could beat the Soviets in this new space age (DeBoer, 1991).

Effects of Sputnik on Science Education

Immediate Effects

Sputnik served as a catalyst for several innovations and reforms for science education in the United States. Among these was the National Broadcasting Company's (NBC) *Continental Classroom*, the first televised attempt at distance learning that aimed at improving the quality of high school science teachers (TIME, 1957). The *Classroom* quickly expanded beyond its original audience and was adopted by 250 colleges and offered as an off-campus course for credit. The American public had also developed a growing interest in science, and the show was popular with a lay audience in 47 states. As a more informal approach to teaching science, summer camps designed around science began to spring up around the country. Sometimes associated with universities, these were facilities where children focused on learning science in a camp-like atmosphere (TIME, 1957). The most important reforms in science education, however, addressed teacher development and curricula.

Recognizing a serious shortage of well-qualified secondary teachers of mathematics and science courses, especially in the area of physical science, the American Association for the Advancement of Science (AAAS) issued a resolution on December 30, 1957 entitled *Training for Secondary School Teachers of Mathematics and Science*. In this document, AAAS called for specialized training for teachers of science because of the substantial differences in subject matter and/or educational methods from other academic disciplines. The resolution also addressed the issue of the shortage of qualified teachers available to teach these science courses for secondary students. Previously, little was being done by schools to encourage students to pursue their interests in scientific and mathematical fields. The report noted the shortage of qualified science teachers, considered the new influx of women in the field, salary inequities between male and female teachers, and the turnover rate of female teachers because of marriage and family responsibilities. Furthermore, there was little agreement on the qualifications that should be required to teach science, including the necessity of an undergraduate degree.

One of the main recommendations proposed by AAAS to address this situation was the establishment of classes designed to teach science by studying its historical development that had been recommended by Conant (1947). Previously, general science courses stressed the human aspects of scientific development and taught the understanding of the scientific process rather than the structure of the discipline itself. This led to the concept of science education as preparation for adulthood and the responsibilities of citizenship as part of a democratic society. Because over 80% of students were not destined for science-based careers, alternatives were designed into the science curriculum that made the subject more life skills oriented. Often debated was the question of whether students who were college-bound needed to take chemistry and/or physics courses, particularly if they were not planning to pursue a degree in one of the scientific fields. In an effort to increase student retention, proponents of the

progressive movement in education won out as physics and chemistry courses began to focus more on practical application rather than on theory, and the use of mathematics in these courses was minimized (Bybee, 1997a).

Science and mathematics education became, in the public's eye, the solution to winning the science and technology race with the Soviet Russia and to regaining global dominance (Eisenhower, 1958). A sense of urgency to improve mathematics and science education became a common theme (Hein, 2006). The emphasis was on making science education a richer and more interesting enterprise for children in hope that increased future enrollments in more demanding studies (e.g., advanced courses, chemistry, physics) would follow.

Although curriculum reform was already underway with the establishment of the Physical Science Study Committee in 1956 (Klopfer & Champagne, 1990), the Soviet Russia's educational system had several advantages over the United States (Bybee, 1997a). The Soviet school year and school week was longer, schools had shorter vacations, and chemistry and physics were fundamental topics taught to every Russian student, frequently beginning prior to high school. Astonishingly, 23% of the American public schools did not offer physics or chemistry. The United States was training half as many scientist and engineers as what was required to catch up with the Soviet Russia (Welch, 1957). To add insult to injury, the output of new science teachers from colleges dropped 57% between 1950 and 1955. Some blamed the drop to poor teachers' salaries. The average salary of a teacher in 1953 was $4,817 per year, whereas individuals working in an automobile mechanic industry made $4,947 per year, and doctors on average earned over $10,000 per year in 1949 (Welch, 1957).

While educational improvements were already underway in the early 1950s (Bybee, 1997b; Hein, 2006), the launch of Sputnik spurred a multitude of changes in science education at both the secondary and the collegiate levels. There was perceived an urgent need for more scientists and engineers that resulted in a call for better qualified teachers and a more challenging science curriculum to be enacted. To meet this need, significant changes were required in curriculum and practice at all levels from elementary through postsecondary. This time became known as the "golden age of science education." Funding for both curriculum development and science teacher professional development (PD) was immediately forthcoming and plentiful through grants, many provided through the NSF, which was now focused on curriculum development (Lacey, 1966; Towbridge & Bybee, 1996). In the post-WWII era, university-level research scientists were the sole determiners of the content that was to be taught in secondary schools (Atkin & Black, 2003), but this changed as the need for new curricula emerged in the post-Sputnik years. Recognizing that instruction needed a strong research base as well as classroom application, teams consisting of researchers and master teachers collaborated to develop and field test new science programs.

Curriculum development became an extensive process and often began with a summer writing conference by a combination of scientists and master teachers. Teachers field tested the new curriculum in their classrooms during the following school year and then worked to revise the curriculum as necessary over a 2–3-year period. The curricula experienced several versions before they were finally ready for publication (Hein, 2006). Once these new curricula were ready, they were turned over to commercial companies for production and distribution. The companies usually provided both traditional texts as well as reform-based curriculum materials. Laboratory investigations were an integral part of the curricula and usually had separate manuals. Examples of these reform curricula for secondary schools include Biological Science Curriculum Study (BSCS), 1958; Physical Science Curriculum Study, 1960; CHEM Study, 1960; Earth Science Curriculum Project, 1967; and Harvard Project Physics, 1970. At the elementary-level reform curricula included Science: A Process Approach (SAPA) 1967; Elementary Science Study (ESS) 1969; and Science Curriculum Improvement Study (SCIS), 1970 (Klopfer & Champagne, 1990; Lockard, 1970). Of these programs, versions of only BSCS and SCIS are still available today.

Even though these curricula are not generally viable today, they were considered effective (Bredderman, 1983; Shymansky, Kyle, & Alport, 1982). Today, the 5E learning cycle is highly recommended. This is an outgrowth of the SCIS three-stage learning cycle (Atkin & Karplus, 1962). The post-Sputnik curricula had strong philosophical foundations such as Piaget with SCIS, Gagne with SAPA, and Bruner with ESS. With the removal of funding by NSF in 1974, sponsored programs for teachers (PD) resulted in declining preparation to implement these innovative approaches.

Once the new curricula were available, funding was needed for PD of teachers. This was often provided through the NEDA and NSF, which allowed for training in content and pedagogy, a stipend for teachers participating in the eight-week summer programs, and graduate credit. Emphasis in the programs was placed on preparing teachers to implement the new curricula; mornings were usually

spent on content development with afternoons reserved for laboratories. PD was national in scope but administered on regional levels (DeBoer, 1991). These PD experiences benefited teachers by increasing their expertise in a particular science discipline, providing them with college credit that could raise their salary and frequently lead to a master's degree. Many secondary teachers who participated in these PD opportunities became department chairs and science education faculty at institutions of higher education.

Schools could obtain equipment needed to implement the new curriculums at reduced rates through NDEA grants, often with schools paying only 5% of the costs, with the government picking up the other 95%. Textbook companies, sensing a lucrative market, partnered with suppliers to develop materials and programs to meet the new demands from school districts. These new programs became big business, and competition for market shares was intense.

Assessment in the United States already had a strong historical background, extending back to its use in determining the placement of recruits for military service during World War I. The implementation of NSF-funded curriculum programs in the decade immediately following the launching of Sputnik brought about the need for evaluation of the effectiveness of these reforms. Determining the results gained from money spent to improve mathematics and science curriculums, therefore, became increasingly important. From this need to assess the effectiveness of the various new curricula, two main camps emerged, those who wanted to test students to assess the value of the program and those who wanted to test the students, but coupled with the objectives of the specific program (Atkin & Black, 2003). In the former, assessing student learning ran the risk of learning a collection of facts that could be easily tested. Assessing student achievement against a set of program objectives required curriculum developers to state their objectives in behavioral terms, in other words, what the student would *do* to demonstrate mastery. Only then, and through the use of appropriate tools, could it be determined to what extent the goals and objectives of the program had been met.

Some concerns were expressed about the constraints placed on a curriculum focused on an overly diligent pursuit and assessment of learning objectives (Atkin & Black, 2003). It was felt that some teachers could feel pressured to pass up spontaneous learning opportunities in favor of meeting the specified learning objectives.

At the time of Sputnik, there were only two science education research journals, *School Science and Mathematics* and *Science Education*. After the launch, the first article referring to Sputnik was written by Panush (1958). The 1958 annual conference for School Science and Mathematics Association (SSMA) focused on methods to explore that analyze methods of teaching K-16 mathematics and science. SSMA was the first science education journal and featured Urey's (1958) observations about long-term educational problems facing the United States. Urey's manuscript was a major presentation at the November 1957 SSMA annual meeting. He challenged the purpose of education, which at the time was "to develop the personality of the individual" and not primarily to acquire knowledge (p. 171). Urey provided five suggestions to improve K-12 schools:

1. reconsider compulsory school age and minimum age for child labor laws;
2. school years should be 10 months, 5.5 days per week, 6 hours daily, plus homework;
3. establishing tracking for special courses in mathematics and science-oriented students (today called tracking);
4. increased financial support for schools; and
5. more and better teachers.

Kidd's (1959) article was the first to use the word Sputnik in a research-focused article. At the 1958 SSMA meeting, Peterson (1959) of the NSF provided detailed description about the specialized programs being developed to improve the quality of science teachers in the United States, including summer fellowships for secondary school teachers and other special projects to promote improved instruction for K-12 science.

In contrast to the monthly issues of *School Science and Mathematics*, *Science Education* was a quarterly journal. In addition to research articles, *Science Education* was the official organ for three science education organizations. These organizations were the National Association for Research in Science Teaching, National Council for Elementary Science (now known as Council for Elementary Science International), and Association for the Education of Teachers of Science (now known as Association for Science Teacher Education). The official minutes of meetings and programs are included in the journal with some references to changes in education occurring in the late 1950s. The first Sputnik-related publication in *Science Education* was President Dwight Eisenhower's January 27, 1958 address to Congress. This address included a summary of the NSF's programs for improving science education.

Long-Term Effects

Sputnik served as an awakening to the need for a more global focus in science education and the need to connect the processes of doing science to all other subject areas (Hein, 2006). Today, the development and introduction of the *National Science Education Standards* (NRC, 1996), *Benchmarks for Science Literacy* (AAAS, 1957), and accompanying state standards help to serve this purpose. These policy documents are profoundly influenced by and build upon the work that was started in the era of curriculum reform in the decade following Sputnik and emphasize the teaching of science through the inquiry process. This process of inquiry offers students a thorough grounding in the scientific processes and is as applicable to mathematics, social studies, and reading as it is to science; however, the meaning of *inquiry* has undergone change (Barrow, 2006). The orientation for inquiry was strongly influenced by the Woods Hole Conference (Bruner, 1960) with the reintroduction of Jean Piaget to the science education community. The post-Sputnik curriculum emphasized separate process skills that were separated from content. This is in contrast to today's approach of processes in context with content (NRC, 1996). Indeed, many teachers are now looking for ways to incorporate inquiry strategies within their classrooms.

Another effect to emerge from the Sputnik era that continues today is the use of kit-based programs especially in elementary classrooms. Numerous curricula are developed around the use of kits and other resources. Today, publishers offer a wide variety of these prepackaged classroom materials and lessons to cover nearly any grade level or science topic imaginable. Today's materials, however, have not undergone the extensive field testing that went into the development of the golden age science curricula.

Conclusion

In the 50 years since Sputnik galvanized the nation and served as a catalyst for improving education in general and science education in particular, far-reaching changes have taken place in all aspects of the educational scene. Perhaps the most significant change has been that of attitude: Whereas in the golden age emphasis was on improving the science curriculum, now the focus seems to be on placing blame for poor performance by students (Hein, 2006). As a community, those involved in all aspects of science education need to acknowledge that the overall purpose of teaching science is not to produce more scientists but to develop children to become better, more informed critical thinkers who are ready to actively participate in the citizenship of a democratic nation.

There seems to exist a cyclical pattern to science education in the United States, alternating between a progressive approach, with its emphasis on social relevance, and a content-driven back-to-basics approach. Reflecting upon science education dating back to the turn of the 19th century, this alternating pattern of opposing educational philosophies has played out with the National Education Association's Committee of Ten (1893), Dewey's pragmatic approach along with the Cardinal Rules (1918), the golden age of science education, and the current return to the new progressivism emphasizing scientific literacy for all (DeBoer, 1991). Within each of these philosophical approaches, education continues until challenged by significant political, social, or economic events, such as Sputnik, which causes a change in trends. If this historical trend is extrapolated, events will occur and cause another change, increasing emphasis on basics in science education. Such a catalyst could be lurking in the No Child Left Behind Act of 2011 (NCLB, 2002) and similar legislation that places emphasis on developing reading and mathematics skills, and a focus on regulatory provisions such as mandatory testing, too often to the exclusion of other classroom subjects, such as science, especially at the elementary level. Legislation often places enormous pressures on classroom teachers to strictly conform to a specific curriculum, leaving little opportunity for experimentation with other science topics, new materials, or instructional methods.

Despite the cyclical nature of "reforms" in science education, increasing concentration should be placed upon knowledge of how individuals learn, (i.e., inquiry) rather than directed by extraneous social, historical, or economic factors. Allowing the direction of science education to be determined by outside pressures is detrimental and costly. However, when students are actively engaged in meaningful investigations, they learn to question, challenge, and make determinations based of evidence and data. Programs that encourage this vision of teaching and learning will help to produce the scientifically literate citizenry required for the next 50 years and beyond. This is the legacy of Sputnik.

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PROBLEMS section

Ted Eisenberg, *Section Editor*

This section of the Journal offers readers an opportunity to exchange interesting mathematical problems and solutions. Please send them to Ted Eisenberg, Department of Mathematics, Ben-Gurion University, Beer-Sheva, Israel or fax to: 972-86-477-648. Questions concerning proposals and/or solutions can be sent via e-mail to eisenbt@013.net. Solutions to previously stated problems can be seen at http://www.ssma.org/publications.

Solutions to the problems stated in this issue should be posted before January 15, 2012

• **5176:** *Proposed by Kenneth Korbin, New York, NY*

Solve:

$$\begin{cases} x^2 + xy + y^2 = 3^2 \\ y^2 + yz + z^2 = 4^2 \\ z^2 + xz + x^2 = 5^2. \end{cases}$$

• **5177:** *Proposed by Kenneth Korbin, New York, NY*

A regular nonagon *ABCDEFGHI* has side 1.

Find the area of ΔACF.

• **5178:** *Proposed by Neculai Stanciu, Buzău, Romania*

Prove: If x, y, and z are positive real numbers such that $xyz \geq 7 + 5\sqrt{2}$, then

$$x^2 + y^2 + z^2 - 2(x + y + z) \geq 3.$$

• **5179:** *Proposed by José Luis Díaz-Barrero, Barcelona, Spain*

Find all positive real solutions $(x_1, x_2, \ldots, x_n)$ of the system,

$$\begin{cases} x_1 + \sqrt{x_2 + 11} = \sqrt{x_2 + 76}, \\ x_2 + \sqrt{x_3 + 11} = \sqrt{x_3 + 76}, \\ \qquad \cdots\cdots\cdots \\ x_{n-1} + \sqrt{x_n + 11} = \sqrt{x_n + 76}, \\ x_n + \sqrt{x_1 + 11} = \sqrt{x_1 + 76}. \end{cases}$$

• **5180:** *Paolo Perfetti, Department of Mathematics, University "Tor Vergata," Rome, Italy*

Let a, b, and c be positive real numbers such that $a + b + c = 1$. Prove that,

$$\frac{1+a}{bc} + \frac{1+b}{ac} + \frac{1+c}{ab} \geq \frac{4}{\sqrt{a^2 + b^2 - ab}} + \frac{4}{\sqrt{b^2 + c^2 - bc}} + \frac{4}{\sqrt{a^2 + c^2 - ac}}.$$

• **5181:** *Proposed by Ovidiu Furdui, Cluj, Romania*

Calculate:

$$\sum_{n=1}^{\infty} \sum_{m=1}^{\infty} \frac{n \cdot m}{(n+m)!}.$$

SSM Publication Guidelines

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Publication Guidelines:
Manuscript length, 6-26 pages including references. In addition, up to 5 pages of tables/figures/appendices will be acceptable. Tables/figures should fit on no more than one page each.

Review Information:
Type of review: Blind review
No. of external reviewers: Three
No. of in-house reviewers: One
Time to review: 6-7 months
Acceptance rate: 20%
Reviewers' comments are returned to the author

Manuscript Topics:

Science, mathematics, and connections between science and mathematics for grades K-graduate and teacher education, especially science and mathematics articles that deal with assessment, attitudes, beliefs, curriculum, equity, research, translating research into practice, learning theory, alternative conceptions, philosophy and history of science, sociocultural issues, special populations, technology, nontraditional forms of instruction, and science/technology/society.

Manuscript Guidelines/Comments:

Submit your manuscript through the ScholarOne site. You will need to register at the site and follow the instructions.

The lead author must be a member of the School Science and Mathematics Association to submit the article and must remain a member in good standing at the time of publication of the paper. Membership information can be found at the Association web site www.ssma.org.

Manuscript Preparation:

All manuscripts must be prepared according to the 6th Edition of the *Publication Manual of the American Psychological Association*. Submissions that are not APA style, or exceed the length limitation, or lack any of the following components will be returned for correction and not reviewed.

1. An abstract not to exceed 200 words on a separate page.
2. Typed double-spaced manuscript using a 12-point or larger font, with 1″ margins top, bottom, and sides. Manuscript should be limited to 25 pages for text and references. Up to 5 additional pages total will be allowed for figures, tables, and appendices.
3. To maintain anonymity, DO NOT include a cover page with author information. In the manuscript, author(s) citing their own work should cite as follows: In text: Author (2007) found… On reference list: Author (2007). *Journal Title*. (Do not include title of article or volume and page #)
4. Graphics should be black type on white background. Do not use color in graphs or figures. Follow APA guidelines for table and figure format and titles. Each table or figure should be on a separate page at the end of the manuscript, with a note within the manuscript where the graphic should be placed. Use no smaller than 8-point font for text on figures; use no smaller than 11-point font for tables. Figures and tables should be no wider than 6.75 inches.
5. A copyright form signed by all authors on the paper to be used by the journal if the paper is accepted for publication. If the paper is rejected, the journal office will shred the form. Up front submission of copyright ensures a timely publication of your manuscript.

Review Procedures:

All manuscripts are subject to a review process. Manuscripts should not have been previously published nor be under consideration for publication in any other journal.

The Editor will use five categories to notify the author of the decision of the reviewer process: Accept, Accept with Minor Revisions, Accept with Major Revisions, Reject and Encourage Resubmission, or Reject. If the decision is to Accept with Revisions, the author(s) are encouraged to complete revisions within 30 days. The revised manuscript will be sent out for review to the same external reviewers as possible.

The manuscript will first be evaluated for fit with the journal guidelines, alignment with APA, and topic alignment with priorities of the journal. The Editor will reject manuscripts that do not adhere to these criteria without review.

Review Criteria:

The following criteria will be used by reviewers in evaluating the appropriateness of manuscripts for publication in *School Science and Mathematics:*

- Relevant, timely, and significant
- Addresses K-graduate science or mathematics education issues
- Explicit, clear, logical, concise
- Reflect current theoretical/literature/practice-based perspectives
- Problem/Research Questions
- Theoretical Framework/Literature Review
- Design/Instrumentation/Procedure
- Data Analysis/Results
- Discussion/Conclusions
- Written presentation/style
- Adds new knowledge

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LETTER FROM the editor

Dear *School Science and Mathematics* (SSM) journal readers:

A critical mass may be considered as the sufficient amount necessary to cause a shift or change that becomes constant. So, I wonder, what would be a critical mass of people needed in the public sector to develop an evolution literate society?

Many universities celebrated Darwin's 200th birthday in 2009. Most universities went public with seminars for laypeople, articles, advertisements, and billboards, taking on the word "evolution" with as much vigor as a new commercial product. Some of the work completed by universities can be found online at http://darwin-online.org.uk/2009.html. While all this was quite interesting, I sat back and wondered, will this help reach a critical mass?

It has been intriguing to see changes in how evolution is approached in American pop culture since 2009. The word "evolution" is used in television, music, printed materials, commercials, and even blogs. Comedy television writers (of such series as "The Big Bang Theory") jokingly have scientists explain evolution, only to have nonscientist characters immediately confuse evolution and science with belief systems. The audience laughs with understanding of the scientist's frustration. On the radio, I still hear *Born from the Shallow End of the Gene Pool* by the Austin Lounge Lizards. While not a new release, this humorous song allows the artist to croon about his own lesser intelligence through natural selection.

News announcers often use the word evolution in multiple contexts, even to describe the condition of the economy. Newspapers print special sections about evolution and Darwin in their science-related news (Wade, 2009). Even commercials announce hair products derived through stem cell research or new products that "evolved." James Madison University mathematician Jason Rosenhouse posts on "EvolutionBlog," where he comments on publications he finds absurd about the evolution and creationism debate. While some of the pop culture uses of evolution espouse misconceptions, at least the "E" word is used. While it seems pop culture has become less fearful of using the word, will it be enough to reach our public sector in understanding evolution?

Fifteen years ago when I first began looking for educational products that thoroughly explained evolution to secondary students, I could only find three high-quality commercial publications and at that time, two of the three were incomplete. Now, the National Science Teachers Association (2011) lists nine quality products on their website for use with students of all ages. The Public Broadcasting Station website publicizes a well-articulated teacher development course, specifically on learning and teaching evolution, narrated by actor Liam Neeson (Zimmer, 2001). Biology Science Curriculum Study lists several products for teachers and students that are activity driven (2011). In 2007, a new scholarly journal titled *Evolution: Education and Outreach*, began offering articles online to assist teachers with research-based evolution education support materials that help with concerns that may be raised by school leaders and parents (Eldredge & Eldredge, 2011).

This is just a small collection of scientifically based evolution education materials currently on the market. Most of these products only discuss evolution theory and history. If evolution theory and history (aka Darwinism) is mostly what is taught, will formal education develop a critical mass of evolution literate citizens (Safina, 2009)?

I thought, what would happen if teachers discussed applied evolution products or technologies in classrooms rather than a debate between religion and science when teaching evolution? What if markets took all the products derived from applied evolution science off the shelf (Hendry et al., 2011)? My head reeled: tomatoes, potatoes, bananas, apples, grapefruits, onions, (okay almost everything in the produce section); beef, lamb, pork, chicken, shrimp (no meats left, except fish from the seas?); processed foods, Twinkies, Goldfish crackers (everything with wheat?). I pondered. Would bottled water even remain on the shelf?

As I continued my search, I came across a cartoon depicting an elderly patient and a young physician. The physician asks, "Before writing a prescription, I must ask if you believe in evolution?" The patient says emphatically, "No!" The physician then hands the patient a prescription and says, "Take these sugar pills twice a day and hope your chronic disease evolves into something less severe."

Then, I read something more serious. Novella (2010), on a blog, describes a series of articles in the Proceedings of the National Academy of Sciences that discusses the

importance of evolutionary biology in modern medicine. Omenn (2010) explains a physician's knowledge of applied evolution in treating obesity, sickle cell anemia, bacterial infections, diabetes and influenza, among a few. Omenn also discusses genetically designed drugs, vaccines, and modification of disease vectors caused by global climate shifts. Perhaps this will get the public's attention to the importance of evolution literacy.

J. J. Bull and H. A. Wichman (2001) published *Applied Evolution*, an article about the recent work and social relevancy of evolutionary biology. The authors not only describe applied evolution benefits from the past but potential uses in hopes of changing public perception of evolution. Bull and Wichman make a case for applying evolution phylogenetics in epidemiology to predict and eradicate diseases. Phylogenetics and DNA fingerprinting have been used in criminal court cases on many occasions (Metzker et al., 2002). Bull and Wichman continue with a discussion on the possibility of directing evolution to stop extinction of targeted organisms or to block evolution, as in the case of HIV. In addition, they describe computational biology (bioinformatics) and underscore its importance in solving large-scale biological problems. However, is human relevancy enough to cause a shift toward an evolution-literate society?

How long does it take for scientific understandings to become part of literate societal norms? During Aristotle's time, around 330 BC, trigonometry and astronomy demonstrated that the earth is round. About 1,000 years later, most people in Europe were convinced that Earth is spherical. Today, only a handful of Americans insist that the earth is flat (Adam, 2010).

A recent survey conducted by Stanford University with Ipsos and Reuters found that 83% of the U.S. population believes global warming is happening, with 72% attributing some cause to human activity (Krosnick & MacInnis, 2011). The Gallup Poll, on the other hand, finds that Americans are still reluctant when it comes to understanding evolution. There is a strong relationship between education and belief in Darwin's theory, as might be expected, ranging from 21% of those with high school education or less to 53% of college graduates, and 74% for those with postgraduate degrees (Newport, 2009). Regardless of educational background, 78% of Americans believe that human evolution was not random, according to a Gallup Poll, while Pew Research Center puts the number closer to 62% (Newport, 2010; AAAS, 2009). According to this information, there seems to be no clear time pattern of acceptance of human evolution by Americans.

It is imperative that science educators help create biotechnology jobs and innovative biotech products in the future through students with a deeper understanding of evolution. So, have we reached a critical mass of population in the United States that has a clear understanding of evolution, especially human evolution and its implications in modern medicine in American society? The answer is clearly no.

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The DESTIN: Preservice Teachers' Drawings of the Ideal Elementary Science Teacher

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The aim of this study is to report findings from the Drawing-Elementary-Science-Teacher-Ideal-Not, or the DESTIN procedure. The study utilizes a simple drawing procedure accompanied by a narrative and discussion for understanding preservice teachers' images of science, science teaching, and the science teacher. Ninety drawings from two sections of an elementary science methods course were analyzed. Looking at the pre-drawings from the beginning of the semester and post-drawings done at the end of the semester, the findings relate the value of using drawings in teacher education and the usefulness of this procedure to promote discussions about science teaching, the construction of new images and practices for teaching elementary science, and teacher identity. The DESTIN procedure has potential as a productive activity for teacher education and long-term professional development by making more explicit teachers' views of science teaching and learning and their past experiences as science learners.

Preservice teachers bring to classroom learning their personal views and perspectives of what science is, what teaching is, what science teaching should look like, and who can do science (Mensah, 2009a). As most images of the scientist are white and male, science teacher educators who emphasize feminist pedagogy and critical perspectives in teaching science try to create learning environments that are inclusive, participatory, and critical of these images (Barton, 1998; Moore, 2007). By presenting different images of science teaching, the image of the scientist may be expanded to include women and women of color.

Researchers have studied the image of the scientist using drawings, questionnaires, essays, and interviews from elementary, high school, and college students, and others have studied these images across cultural borders (Beardslee & O'Dowd, 1961; Chambers, 1983; Rahm & Charbonneau, 1997; Rampal, 1992; Schebeci & Sorensen, 1993). The perceptions of scientists held by children and others are related to attitudes toward science, perceptions of school science, and self-efficacy (Barman, 1999; Finson, 2000; Finson, Riggs, & Jesunathadas, 1999; Hammrich, 1997; Kahle, 1988; Zeldin & Pajares, 2000). In these studies, researchers have noted that images of the scientist were consistent with many of the stereotypical images of the scientist found from the classic study of American high school students (Mead & Metraux, 1957), and from Chambers' (1983) drawing procedure, the Draw-A-Scientist Test (or the DAST). The composite portrait of the scientist from these classic studies is widely known: the white male, wearing a lab coat and eyeglasses, having facial hair, with symbols of research, and symbols of knowledge, technology, and relevant captions. While interpreting drawings from the DAST, additional characteristics were identified, such as scientific instruments, signs of danger, light bulbs, basement or underground laboratories, male/female figures, and mythical images or stereotypes. Of the 4,807 drawings done by students (kindergarten to fifth grade) in the United States and Canada, Chambers noted that only 28 of the drawings depicted female scientists. Chambers also found that various elements of the stereotypic image of the scientist increased with grade level.

Similarly, researchers have looked at negative images and personal qualities of the scientist. In one study, Beardslee and O'Dowd (1961) found from unstructured interviews that college students possessed images ranging from the scientist as "unsociable, introverted, and possessing few, if any, friends" to "being dedicated to his work and carrying it out with heroic devotion at the expense of concern with public affairs and even family responsibilities" (p. 997). The scientist had "high intelligence," "precision in thinking," and "objectivity (that is, lack of emotional involvement) with which he handles most personal and professional problems" (p. 997). Among other qualities, the scientist had a "need to proceed in his work regardless of other demands on his time" (p. 997). When the researchers administered a questionnaire to solicit more responses, they found additional characteristics of the scientist. From a small group of college faculty of science and faculty of the social sciences, the images from these groups revealed similar information from the interviews and questionnaires administered to the college students. The researchers concluded that the image of the scientist had an effect of "recruiting a certain type of person and discouraging others," and the public's reaction

was "colored by this image" (p. 1000). Thus, the image of the scientist may seriously impact who enters into science and how others see scientists.

Furthermore, studies of the image of the teacher generally have had similar results to those of the scientist. The teacher image comes from a variety of sources, including teachers themselves (Joseph & Burnaford, 1994). Researchers have discussed several sources of negative portrayals of teachers, such as television and film, or from newspapers and scientific journals (Harris, 1989; Mason, Kahle, & Gardner, 1991; Pion & Lipsey, 1981). These media-inspired teachers represent stereotypes that place high expectations and stress on real classroom teachers. The media also depict teachers through subliminal messages, which are not easy to capture. Damaging stereotypes portray teachers, predominantly as females, as unrealistically incompetent, antagonists of the principal, superhuman social workers, and perfect, always considerate, resourceful, and energetic. In order to counteract negative stereotypical portrayals of teachers, Swetnam (1992) advised that citizens become more involved in schools as volunteers, mentors, and advisory board members, so that they become better informed about life in schools. Likewise, Finson (2002) recommended informing teachers of stereotypical elements, conducting action research projects, having classroom discussions, and educating science colleagues about these views.

Weber and Mitchell (1996) stated, "While images always maintain some connection to people, places, things, or events, their generative potential in a sense gives them a life of their own, so that we not only create images, but are also shaped by them" (p. 305). When teacher candidates enter teacher education, they have a well-established teacher-role identity. These identities come from years of being a student and participating in the process of schooling. Knowles (1992), for example, noted that preservice teachers and beginning teachers' thinking about teaching and their classroom practice is partially shaped by their prior experiences and a lifetime of socialization into teacher education. As an illustration, Weber and Mitchell studied drawings done by student teachers and experienced teachers in order to understand past and present influences on the development of teacher identity. By exploring stereotypes and contradictions in the images that the teachers drew, Weber and Mitchell found that preservice teachers held very traditional and stereotypical images of teachers. In discussing their images, the preservice and experienced teachers were able to reframe personal choices around teacher identity. Having an awareness of the multiple social influences on their images and emerging teacher identity were powerful in allowing the teachers to make more conscious and more personally meaningful choices in evaluating, challenging, and reflecting on stereotypical images, which are developed from historical, social, cultural, and personal stereotypes.

The images of the scientist and the teacher hold much concern for preparing elementary science teachers, with the majority of them being female. However, many of their past experiences in school science, especially in high school and college, have shaped their current views of science teaching, and many of their views are not positive. Largely, science teacher educators are responsible for creating learning environments that show preservice teachers alternative conceptions of science and science teaching (Mensah, 2009a). In other words, preservice teachers must reveal and confront their perceptions of science teaching toward developing more positive images of science and the science teacher. This is important because when teachers have negative images of science teaching they are likely to pass these images on to their students and manifest these images in their teaching practice (Finson, 2002; Rosenthal, 1993). Weber and Mitchell (1995) suggested that teacher education should not focus on "overcoming" or "unlearning" past experiences of the traditional views of teaching, but rather should work to "undo" prior knowledge. Considering the results of the DAST and previous research on images of the scientist and images of the teacher, this study used a simple drawing procedure to elicit conversations on images of science, science teaching, and the science teacher.

Purpose of the Study

The aim of this study is to report findings from the DESTIN procedure. First, the study looks at pre-drawings and post-drawings done by elementary preservice teachers. Second, the study reports the usefulness of the DESTIN procedure to promote discussions about science teaching and the construction of new images and practices for teaching elementary science. Researchers have cited that elementary teachers are not strong in content knowledge, inquiry practices, scientific literacy, and have low confidence for teaching science (Bianchini & Colburn, 2000; Gunning & Mensah, 2010; Harlen, 1997; Howes, 2002; Rice, 2005). The drawing method and analyses provide insights into preservice teachers' prior thinking, science learning experiences, and emerging identities as elementary science teachers. Research on images and identity is an interesting avenue for understanding preservice elementary science teachers with respect to science education.

Methodology

Setting and Participants: Elementary Methods Course

In an urban, northeastern graduate school of education, 54 preservice teachers within two sections (fall and spring) of an elementary science methods course were participants for this study. The ages of the preservice teachers ranged from 22 to 37 years and were enrolled in the science methods course as part of their initial teacher certification program. The two sections were predominantly female, which is typical of elementary teacher candidates. The self-reported gender and racial/ethnic backgrounds of the 54 preservice teachers were 48 females: 29 White/Caucasian/European American; eight Asian/Southeast Asian/Korean/Chinese American; two Middle Eastern American; two African American; one French American; one Native American; one Latina American; one African American Latina; one Indian-South Asian; one Italian Lithuanian American Indian; and one Caucasian Croatian. There were also six males: four White/Caucasian/European American and two Asian-American. Two preservice teachers were registered with the Office of Disabilities, and all students were fluent and communicated in Standard American English.

Within the 16-week elementary science methods course, the preservice teachers participated in a range of course assignments and field-based experiences such as interviewing a child on a science topic, weekly observations in an urban elementary classroom, and planning, teaching, and assessing a science lesson (microteaching) that was taught in the university setting or in an elementary classroom. The course also promoted educational theory and practice, teaching science for understanding, using inquiry-based science instruction, and issues of diversity in science education. As a science educator of this course over the years, preservice teachers enter the course holding preconceptions and negative views of science and science teaching (Gunning & Mensah, 2010; Moore, 2007, 2008; Mensah, 2009a). Few are able to share positive experiences of science learning. Therefore, I wanted to stimulate conversations more formally around stereotypes and negative perceptions of science teaching through drawings. In order to promote these types of conversations about science teaching and to discuss where the preservice teachers' negative images came from, the DESTIN procedure was developed.

Introducing the DESTIN

The DESTIN was developed to explore elementary preservice teachers' images of science and science teaching. The drawing procedure for the DESTIN was derived from a review of literature relating the image of the scientist and the teacher (Barman, 1996; Beardslee & O'Dowd, 1961; Chambers, 1983; Finson, Beaver, & Cramond, 1995). The DESTIN procedure considered many of the suggested strategies for understanding teachers' drawings, such as using a standardized procedure and a narrative component. In developing the procedure for the DESTIN, I wanted to start with a question that was focused on negative images of science teaching in order to stimulate a personal discussion about the preservice teachers' experiences as learners of science (pre-drawing), and then have the second question to focus on new images of science teaching (post-drawing). Specifically, the DESTIN consists of pre- and post-drawings. The pre-drawing, or the *ideal science teacher-not*—or the teacher that they would not want to become—is drawn on the first day of class. The post-drawing is completed at the end of the semester, and preservice teachers draw the *ideal science teacher*—or the science teacher that they would like to become.

The DESTIN Procedure

On the first day of class, the elementary preservice teachers were given a blank sheet of white paper. Using a transparency, they were instructed for the pre-drawing to: "Draw the image of the *ideal science teacher-not*—the science teacher that you would not want to become. On the front or back of the sheet, list some characteristics of this science teacher or reasons why you do not want to become this science teacher." No additional prompts were given to the preservice teachers; however, they were allowed to list qualities if they did not want to draw a picture, and they were asked to write their names on their drawings. After the drawings were collected, a large group discussion was conducted where they discussed negative and stereotypical images of science, science teachers, and science teaching. I wrote descriptive words on a transparency and encouraged the preservice teachers to talk about where these negative and stereotypical images came from and how they felt as science learners in the classrooms of the *ideal science teacher-not*. In several instances, they shared past experiences in learning science in K–16 classrooms and indicated that they had experienced science teachers and classroom environments similar to those depicted in their drawings.

For the post-drawing done during the last day of class, instructions were the same as the pre-drawings, except preservice teachers were instructed to: "Draw the image of the *ideal science teacher*—the science teacher that you would like to become. On the front or back of the sheet, list some characteristics of this science teacher or reasons why you would like to become this science teacher." The preservice teachers were given no additional prompts; however, they were given the option to list qualities if they

did not want to draw a picture, and they were asked to write their names on their drawings. Rather than writing descriptive words for the post-drawings on a transparency like on the first day of class, students participated in a whole class discussion where they shared their experiences in teaching and learning science over the semester. All the preservice students did a science microteaching lesson in an elementary classroom or in the university classroom, and many of them discussed their microteaching experience and made connections to how their views of science changed over the course of the semester, and how they developed an emerging identity as elementary science teachers. These new ideas were displayed in their drawings.

Analysis of Drawings

The open-endedness of the task allowed the drawings to be analyzed in several ways. From both procedures, 90 drawings (49 pre-drawings, 41 post-drawings) and four descriptive narratives with no images (one pre-drawing, three post-drawings) were gathered. The drawings were analyzed to identify science teacher characteristics that represent the *ideal elementary science teacher-not* and the *ideal science teacher*. The drawings were not evaluated on merit of artistic skill, but served as symbolic representations and visual images to be read as "text" (Fiske, 1989; Kress & Van Leeuwen, 1996). The analysis of drawings provided details about science, the science teacher, and science teaching. Additionally, the drawings showed how preservice teachers perceived issues of diversity and their own identities as elementary science teachers.

To begin the first level of analysis of the 90 drawings and four descriptive narratives, two checklists were created in order to write a profile of the image of the science teacher. For example, a list of common descriptors was compiled from the narratives that accompanied the preservice teachers' drawings and was tallied for quantitative measure. The most frequently mentioned descriptors (three or more) were used to construct a narrative profile of the *ideal elementary science teacher-not* and the *ideal elementary science teacher*.

After gathering information to construct a profile, a more careful coding procedure was developed for analysis of all 90 drawings. Only three of the 90 drawings were simple stick drawings with no narrative descriptions, or were ambiguous in identifying the image (i.e., only a stick person or only a face smiling). The drawings were "read" or categorized using a seven-point analysis or criteria checklist, which was based on findings from the DAST and from literature on multicultural education and identity. Three coders (two science education faculty and one doctoral student) wrote descriptive notes that were compared with the researcher. At another time, two additional coders (doctoral students) coded the drawings using the seven-point criteria checklist. The notes from these coding stages were compared and discussed. Using the notes from that meeting, the seven-point criteria were collapsed into three criteria (Table 1). The three-point DESTIN criteria were used to analyze systematically all of the drawings once more and to classify them for discussion of findings.

Table 1
DESTIN Criteria

Criteria	Description
Stereotypical/ Traditional Images:	Having two or more of the criteria from DAST-C; having straight rows, desks, or chairs, blackboard, tables, books, science equipment; physical appearance of teacher with hair in bun, conservative attire, eyeglasses, white, middle-aged to elderly, teaching/standing in front of the classroom.
Alternative Images:	Showing alternative conceptions or nontraditional to teaching science: science teaching outside classroom, students sitting on floor, student–student interactions, students as active learners, collaborative learning, mentions "student-centered" learning on drawings or in narrative; mentions the word "science" or "exploration" or "discovery" on drawings or in narrative, ask inquiry-based questions, mentions other related science terms, concepts, or content.
Diversity and Identity:	Having gender, race/ethnicity, age, disability of students, awareness of diversity in terms of science teaching, assessment methods, learning styles, students' backgrounds and culture; mentions "diversity" on post-drawings or in narrative; mentions "self" or "me" or "my" or "I" in the post-drawings or in the narrative, or responds "yes" in class when asked if the drawing was a self-image.

DAST-C = Draw-A-Scientist Test Checklist.

Findings

The findings represent the analysis of the drawings of the *ideal elementary science teacher-not* pre-drawings and the *ideal elementary science teacher* post-drawings. The findings are grouped according to the three DESTIN criteria, along with representative images as exemplars.

Profiles of the Elementary Science Teacher

The Ideal Elementary Science Teacher-Not. The overwhelming majority of the drawings (72 drawings, 80%) were images of female science teachers. This was not surprising because the participants were predominantly female preservice teachers. From the narratives that accompanied the drawings, two lists of common descriptions were compiled in order to create a profile of the *ideal elementary science teacher-not* (pre-drawing, Figure 1) and the *ideal elementary science teacher* (post-drawing, Figures 2–4). In the composite profile, the descriptive characteristics most frequently stated in the preservice teachers' narratives and appeared three or more times on the list were used to write the profile. The actual descriptive words of the teachers are given in quotation marks: The image of the *ideal elementary science teacher-not* was a female, middle-aged teacher; she was "boring" and "mean"; she assigned "too much work"; she was "standing and lecturing" to the class, and was "not student-centered"; she was "impatient" with her students, and she has low expectations for their success; the *ideal elementary science teacher-not* was an "authoritative" person who disciplines by always "yelling" such things as "Sit down!" and "Shut up!"; her students were not happy because the class was "boring"; she would speak, "blah, blah, blah" but her students did not get anything out of the science instruction, or they would use class time to sleep; overall, the *ideal elementary science teacher-not* was "uncreative" and "does not enjoy her job."

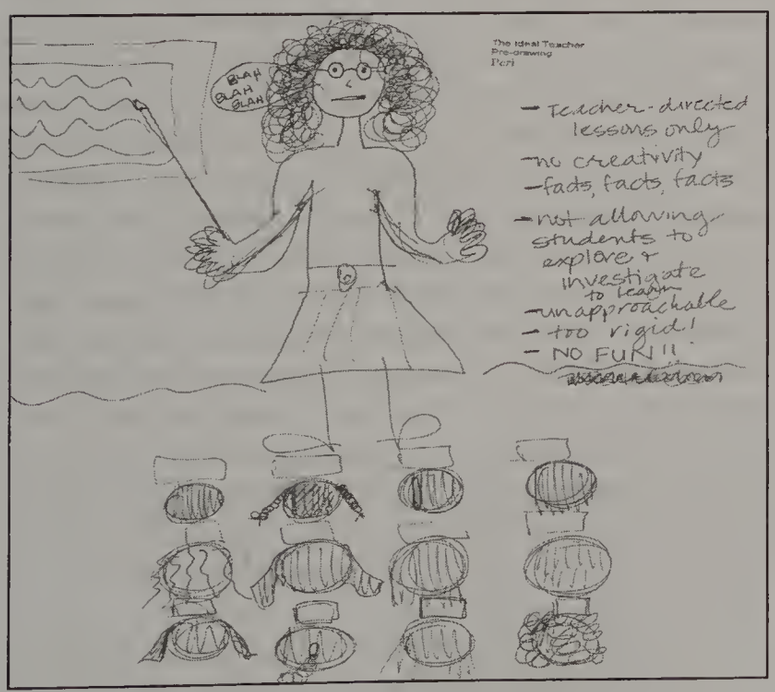

Figure 1. Peri's pre-drawing.

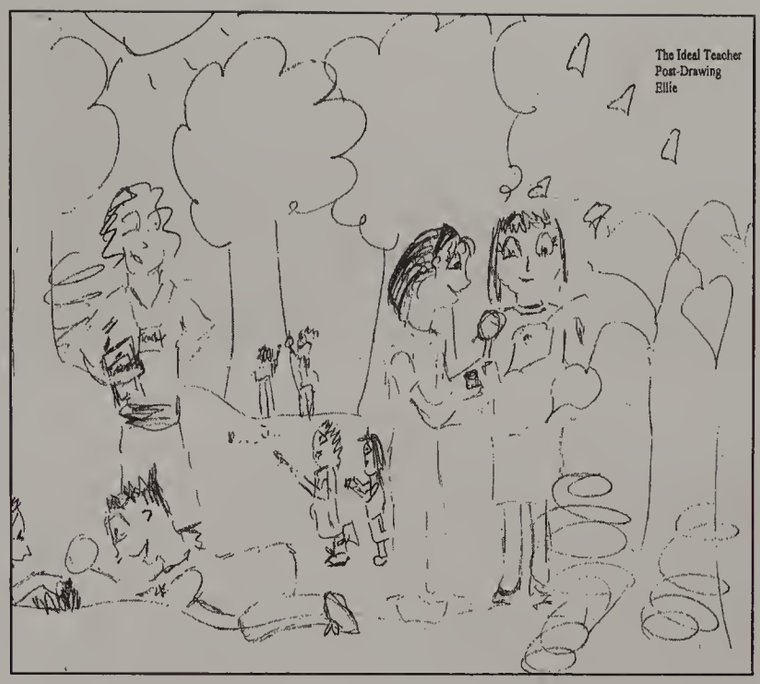

Figure 2. Ellie's post-drawing.

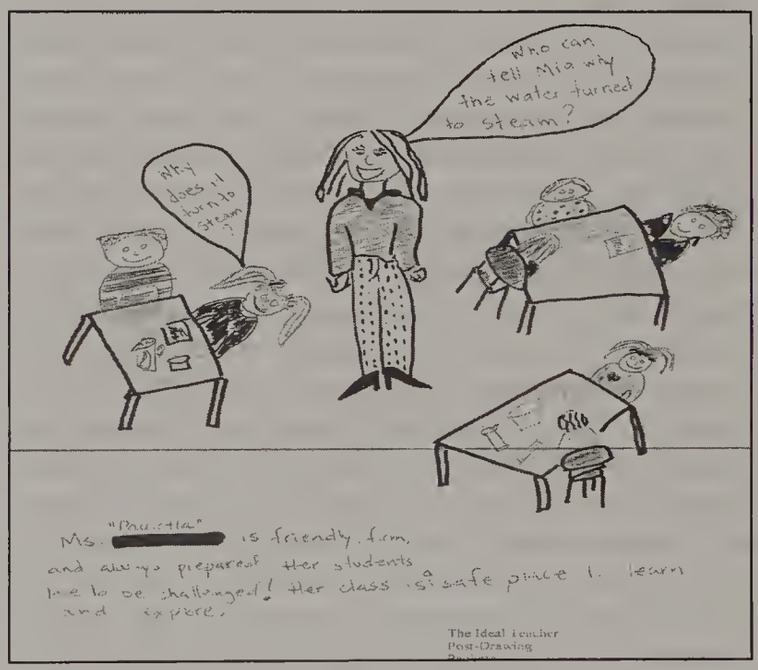
Who can tell Mia why the water turned to steam?
Why does it turn to steam?
Ms. "Pauletta" [redacted] is friendly, fun, and always prepared! Her students have to be challenged! Her class is a safe place to learn and explore.
The Ideal Teacher
Post-Drawing

Figure 3. Pauletta's post-drawing.

The Ideal Elementary Science Teacher. Conversely, the composite profile of the *ideal elementary science teacher* was more positive. The descriptive words (three or more

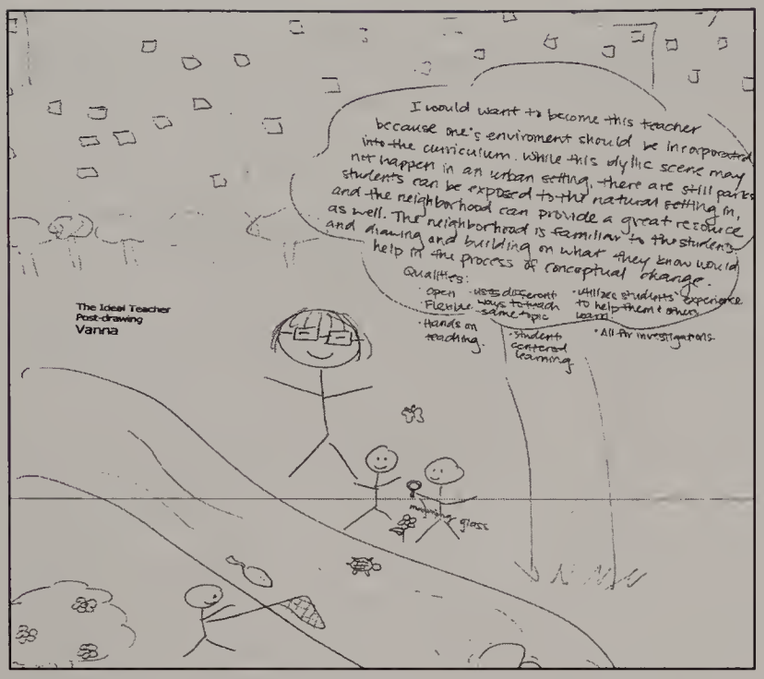
I would want to become this teacher because one's enviroment should be incorporated into the curriculum. While this idyllic scene may not happen in an urban setting, there are still parks and the neighborhood can provide a great resource as well. The neighborhood is familiar to the students and drawing and building on what they know would help in the process of conceptual change.
Qualities:
· open
· Flexible
· hands on teaching
· student centered learning
· All for investigations
The Ideal Teacher
Post-drawing
Vanna

Figure 4. Vanna's post-drawing.

times) given by the preservice teachers were used to construct this profile: The image of the *ideal science teacher* was "fun," "energetic," "enthusiastic," and "excited" about teaching science; she was "warm," "encouraging," and "welcoming" of her students; the *ideal teacher* could "connect to students" because she was "involved with the students" by forming "good relationships with her students"; her students saw her as "approachable" and "students trust her"; the *ideal science teacher* would "build on what students know by using students' experiences"; the teacher had a very "active," "hands-on," "student-centered" classroom; she was not limited to teaching just in the classroom but science teaching and learning could be conducted "outside the class," where science was "connected to the students' world"; the *ideal teacher* was "culturally aware and conscious of diverse students"; she was "understanding" and "tolerant of diverse students and learning styles"; overall, the *ideal science teacher* was "accepting," "respectful," and she "makes the classroom a safe place to learn."

Criterion 1: Stereotypical/Traditional Images of School Science Teaching

Pre-Drawings of Science Teaching. The pre-drawings of the *ideal elementary science teacher-not* were traditional, dominant images of the science teacher as knowledge giver or knowledge provider. The students appeared to be distant from the teacher. For example, the students were seated in straight rows, passively receiving knowledge from the *female* science teacher, who was the knowledge giver, writing science facts on the board (Figure 1). In several of the drawings, a lecture-style classroom, similar to a large lecture hall one would find in many undergraduate science courses, showed the teacher in front of the classroom, at the board, talking-teaching science. Thus, the image of school science was dominated by fact-giving, lecture-style, didactic approaches. None of the 49 pre-drawings depicted group collaborations in teaching and learning science. In some cases, students were not drawn at all. Surprisingly, "science" was written in only eight (16%) of the 49 pre-drawings narratives. In class discussions, preservice teachers recalled few opportunities when they were actively engaged in science as learners, and they mentioned "memorization" as the most common strategy for learning science.

Criterion 2: Alternative Images of Science Teaching

Post-Drawings of Science Teaching. The images were also coded for alternative images of science teaching. The ideas of social interaction, building on what students know, asking students questions, and making science teaching more welcoming and exciting can be read from the post-drawings. For example, the post-drawings showed more student-centered, inquiry-focused, and collaborative learning environments with students working in small groups (Figures 2 and 3). Additionally, science teaching and learning extended beyond the classroom walls, where teachers and students were outside of the classroom, such as in the park or on the school grounds. There was no blackboard, and the science teacher typically was not standing in the front of the classroom. She moved among the students, interacting with them. Thus, the preservice teachers displayed broader or alternative views of science teaching, and the role of the science teacher was facilitator and guide.

Additionally, in the post-drawings of the *ideal science teacher*, there were 23 (47%) post-drawings which represented notions of "doing science." This was captured by descriptions such as "scientific," "explore" or "science content knowledge" written on the drawings or in the narrative. Several drawings showed the science teacher asking inquiry questions, while other drawings had science tools, such as beakers, magnifying glasses, and rulers on the tables. As an example, one preservice teacher wrote in her narrative of the *ideal science teacher*: "uses real examples/contexts, environments that students can relate to, and presents problems or questions for students to answer using science as a tool to exploring their world."

Criterion 3: Diversity and Identity of Student and Teacher

Post-Drawings of Science Teacher. Race/ethnicity, gender, and physical disability were read and coded in the pre-drawings and the post-drawings. Twenty-two (54%)

post-drawings had students with identifiable diversity/identity markers; only three (0.6%) pre-drawings showed these qualities. Charlotte, a European American female, drew the only image of students with physical disabilities in her post-drawing; these students were sitting in wheelchairs.

The preservice teachers were asked to indicate if their post-drawings were self-portraits. Twenty-one (51%) of the *ideal science teacher* drawings were self-portraits, showing physical features such as shaded faces (darker skin tone), braided hair, almond-shaped eyes, and identifying "me," "my," or "I" in the drawings. Included among the self-portraits was one male image. This indicated that at the end of the semester, the preservice teachers were representing themselves as the *ideal elementary science teacher*. For example, the drawings showed young, fashionably dressed elementary science teachers. The nonconservative hair and attire represented the culturally embedded images of what an elementary science teacher looked like as someone more aligned with who they were currently—young, modern, and probably less identifiably conservative in traditional or stereotypical images of the science teacher. For instance, Sonja's image was a self-portrait of a fashionably dressed teacher with an upswing haircut, V-neck blouse, miniskirt, pointed-toe shoes, and makeup.

Pauletta, an African American preservice teacher, drew herself as a fashionably styled, nonconservative teacher (Figure 3). Particularly notable about the image is that Pauletta drew herself with shaded face (darker skin color) and dreadlocked (braided) hair. She also added dialogue boxes of conversations with her students. For science instruction, Pauletta—the *ideal elementary science teacher*—questioned her students about water. This was a similar question she posed to her peers during her in-class microteaching lesson on the water cycle. She also shaded the faces of some of her students, representing their racial/ethnic background, or darker skin tone; and she drew three girls and three boys, representing gendered students. In this post-drawing, she was engaging her students, who were sitting in small groups at tables, not the traditional desks lined up in a row, in a science experiment; tools were drawn on the tables.

Similarly, Vanna's image of the *ideal teacher* was a self-portrait of an Asian-American female science teacher, who was wearing glasses, because she wore glasses (Figure 4). She identified herself as "me" and "I" in the drawing. However, her students have no gender, race/ethnicity, or physical disability. Vanna's drawing showed science in a nontraditional classroom setting. She wrote in detail about teaching science where "one's environment should be incorporated into the curriculum." Vanna also acknowledged the diverse learning styles of her students and the communities that they came from in helping them to learn science. She wrote, "The neighborhood is familiar to the students and drawing and building on what they know would help in the process of conceptual change"—a concept that was covered in course readings and classroom discussions. Thus, the drawings that the preservice teachers completed depicted their views of science, teaching, and self.

Discussion

To better understand the perceptions and views that preservice elementary teachers have about teaching science as a subject matter, the characteristics and qualities a science teacher has, and what good science teaching looks like, the DESTIN was developed and implemented in two sections of an elementary science methods course. The pre-drawing procedure generates images from the past and serves as a critical point of conversation, while the post-drawing procedure solicits positive images as preservice teachers imagine themselves as future science teachers. In both drawing procedures, opportunities are given to the preservice teachers to broaden their notions of what it means to teach elementary science as well as to consider the possibility that they themselves can be the image of the *ideal elementary science teacher*. The findings from the DESTIN procedure provide valuable information in at least three important ways regarding school science teaching and teacher identity.

First, the pre-drawings (the science teacher that you would not want to become, the *ideal elementary science teacher-not*) reveal negative, traditional, and stereotypical images of science and science teaching. Although we begin from this negative image, they foster much dialogue. The preservice teachers describe science learning as "boring" and "not student-centered," and the primary mode of science instruction is "lecturing" and "memorization." They draw students sitting in straight rows, facing front, and there is no interaction between the teacher and students. The power dynamics in the classroom are very much controlled by the science teacher, and the teacher does not promote, accept, or welcome diversity. Definitely, these are not images or teacher characteristics that are desired for culturally diverse classrooms (Gay, 2000; Irvine, 2003; Ladson-Billings, 1994, 1995). Regrettably, these images of school science coincide with stereotypical and traditional images of the scientist, the schoolteacher, and classroom practices found in earlier studies (Dooley, 1998; Finson, 2002; Hancock & Gallard, 2004; Mead,

1951; Thomas, Pedersen, & Finson, 2001; Weber & Mitchell, 1996). In fact, the preservice teachers reveal that their drawings reflect their past experiences as science learners. Unfortunately, few of the preservice teachers speak of positive science experiences as science learners.

Second, the post-drawings (the science teacher you would like to become, the *ideal elementary science teacher*) reveal nontraditional images of science teaching. The post-drawings illustrate reform initiatives for teaching science as inquiry and teaching science that attends to the diverse needs of students (Atwater, 1995; Mensah, 2009b; National Research Council, 1996, 2000). For example, the drawings show school science outside of the classroom, such as on the school grounds, in the park, or by a stream. The drawings show inclusion of more student-centered learning environments, such as students working in small groups, engaging in inquiry-based learning, and asking questions. The preservice teachers view science as asking questions, learning about the world around them, using tools of science, and talking and doing science, even outside of the classroom. Overall, the post-drawings of the *ideal elementary science teacher* show conceptually broader representations of school science and student-centered methods of teaching science.

Third, the preservice teachers indicate in their post-drawings and narratives and during classroom discussions that they want to be more aware of issues of diversity in science teaching. These connections to diversity and identity are unique to the DESTIN procedure analysis and are not found in other drawing procedures, which typically focus only on images of the scientist or science teaching in general. Diversity and identity in the drawings show that preservice teachers acknowledge race/ethnicity, gender, class, age, or disability of students. The preservice teachers also mention being an "agent of change" in the science classroom and indicate more inclusive science teaching approaches. Their pedagogical practices include valuing skills and knowledge that students bring to the science classroom, acknowledging different learning styles of students, and assessing students in various ways. The course promotes multicultural education and issues of diversity; yet prior to the course, these connections are absent.

In addition to diversity, the preservice teachers draw images of themselves as science teachers. These images are more aligned to who they are and allude to experiences they had in the science methods course. The images of the *ideal elementary science teacher* represent the changing face of teacher education as preservice teachers draw science teaching images that are more culturally responsive to elementary learners (Gay, 2000), and "progressive" in terms of how they represent self (Weber & Mitchell, 1996); they draw self-portraits of young, fashionably dressed, culturally sensitive science teachers. These images connect to who they are as individuals and represent their positive learning experiences over the semester. The drawings illustrate personally meaningful representations of science teaching for the preservice teachers and the students they will teach. Therefore, the analysis of the images that the preservice teachers draw regarding diversity and identity is a unique feature of the DESTIN procedure. The analysis conveys broader views and conceptions of science teaching, student diversity, and teacher identity, which are read from the drawings.

Implications and Conclusion

This study utilizes a simple drawing procedure accompanied by a narrative and group discussion for understanding preservice teachers' images of science, science teaching, and the science teacher. Though this study highlights drawings done by a small sample of 54 elementary preservice teachers enrolled in a science methods course, the study relates the usefulness of analyzing images in teacher education (Chambers, 1983; Weber & Mitchell, 1996). Drawing teacher images provide researchers and educators an opportunity to examine a few "snap-shots" or "windows" into individual thoughts, views, and experiences, including their learning in teacher education courses. Hence, the DESTIN procedure has potential as a productive activity for teacher education and long-term professional development by making more explicit teachers' past experiences as science learners and their views of science education. It is not only a beneficial technique in exploring why elementary preservice teachers feel negatively about science but also offers opportunities for them to discuss more positive images of themselves as science teachers and their students' engagement in school science, particularly from learning in a methods course. As seen in this study, many preservice teachers draw themselves as the *ideal elementary teacher*, thus implying that they can imagine themselves as successful elementary science teachers and envision positive examples of science teaching.

To add to the conversation on drawings used in science teacher education, preservice teachers need new avenues to express their views. They also need to move beyond negative and stereotypical images toward the construction of more positive images of science teaching, student diversity, and teacher identity in science education. The opportunity for preservice teachers to think about new images of science teaching is evident from their participation in

science methods courses (Gunning & Mensah, 2010; Mensah, 2009a; Moore, 2008). Weekly observations, microteaching in elementary classrooms, and open discussions about the importance of science in the elementary school curriculum are also influential in providing a context in which to explore new images of science teaching and the development of a science teacher identity (Gunning & Mensah, 2010). The methods course encourages all preservice teachers to develop a science teacher identity, especially one that attends to the diverse needs of students. Thus, the learning acquired from the methods course is represented in the images as well.

As preservice teachers develop alternative, more positive images of science teaching, these newer images can serve as a basis for imaging their future identities as science teachers. The post-drawings, for instance, invite the preservice teachers' sense of "imagination" through a creative process of "generating new relations through time and space that become constitutive of the self" (Wenger, 1998, p. 177). In other words, the drawings of the ideal science teacher are how "we conceive of new developments, explore alternatives, and envision possible futures" (p. 178). These images and drawings are indeed important representations for elementary preservice teachers to think about, imagine, and draw in science education. By presenting different images of science and science teaching, stereotypical depictions are obliterated and replaced with more inclusive, alternative images that are progressive, positive, and inviting to teachers and students.

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Key Words: teacher education; elementary teachers; drawings; identity; science education

Student Strategy Choices on a Constructed Response Algebra Problem

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A central goal of secondary mathematics is for students to learn to use powerful algebraic strategies appropriately. Research has demonstrated student difficulties in the transition to using such strategies. We examined strategies used by several thousand 8th-, 9th-, and 10th-grade students in five different school systems over three consecutive years on the same algebra problem. We also analyzed connections between their strategies and their success on the problem. Our findings suggest that many students continued to struggle with algebraic problems, even after several years of instruction in algebra. Students did not reflect the anticipated growth toward the consistent use of efficient strategies deemed appropriate in solving this problem. Instead a surprisingly large number of students continued to rely on strategies such as guessing and checking, or offered solutions that were unintelligible or meaningless and not useful to the researchers. Even those students who used algebraic strategies consistently did not show the anticipated improvement of performance that would be expected from several years of continuing to study mathematics.

Students' learning of algebra and algebraic reasoning has long been recognized as playing a fundamental role in exploration of most areas of mathematics, as a goal of school curricula, and a focus of mathematics education research (Carraher & Schliemann, 2007; Kieran, 2007). Currently, several documents are again reemphasizing the importance of algebra, especially in the secondary curriculum. *Foundations for Success* (National Mathematics Panel, 2008) drew attention to the importance of students possessing the fundamentals of algebra, because competence in algebra is acknowledged to be the gatekeeper for continued study of mathematics. A central core of the report was focused on what should be done to prepare students for success in secondary algebra courses.

The National Governors Association Center for Best Practices and Council of Chief State School Officers (2011) have published the "Common Core Standards" in mathematics with the intent that each state adopt the standards and common assessments based on them. The standards highlight expectations for what students should know when they complete secondary school in order to be prepared for college and career. These standards include an emphasis on algebraic reasoning, as 2 of the 10 standards focus on expressions and equations. They state that students should be able to make sense of quantities in problems and formulate equations to solve problems.

The National Council of Teachers of Mathematics' *Focus in High School Mathematics: Reasoning and Sense Making* (2009) also emphasizes secondary students' learning to use algebra to solve problems. They write,

> Problem solving with equations should include careful attention to increasingly difficult problems that span the border between arithmetic and algebra. Such problems can help students view algebra as a sense-making activity that extends one's problem-solving skills into domains in which reasoning as done in arithmetic gets too complicated or cumbersome to carry out. Seeing the essential parallels between algebraic and arithmetic solution methods can help students gain confidence that algebra is . . . a more powerful tool for dealing with problems . . . (p. 32)

They also argue that as students seek to use algebraic solution methods, they should be purposeful in their strategy selection, review their chosen strategies, and change strategies when necessary.

A valid, pertinent, and necessary goal for students in secondary mathematics coursework is a transition from arithmetic to algebraic ways of solving problems (Van Dooren, 2002; Van Dooren, Verschaffel, & Onghena, 2003). As Van Dooren (2002) noted, "When students move from primary to secondary school, the acquisition of an algebraic way of mathematical reasoning and problem solving is one of the most important mathematical learning tasks" (p. 319). Carraher and Schliemann (2007) noted

others' claims that the algebraic method is a more effective and natural way for solving problems than the arithmetic method. They argued that arithmetic, numerical, and quantitative reasoning can be an entry point into algebra and algebraic reasoning, because arithmetic has an inherently algebraic nature. Slavit (1999) also demonstrated how students' understanding of arithmetic operations formed the roots of algebraic thought.

Despite this potential, researchers have noted that the transition from arithmetic to algebra is difficult for many students (Carraher & Schliemann, 2007; Herscovics & Linchevski, 1994; Kieran, 2007; Stacey & MacGregor, 2000; Van Amerom, 2003; Van Dooren, 2002; Warren, 2003). Students' arithmetic background influences their ability to transition to algebraic reasoning, and students making this transition often lack understanding of the mathematical structure underlying the arithmetic they have learned (Linchevski & Livneh, 1999; Warren, 2003). For example, Steele and Johanning (2004) found that students struggled in solving problems when they could not move beyond considering particular cases to a consideration of the structure underlying the relationships in the problems. Stacey and MacGregor (2000) showed that ". . . at every stage of the process of solving problems by algebra, students may be deflected from the algebraic path by reverting to thinking grounded in arithmetic problem solving methods" (p. 149). Van Amerom (2003) noted that students generally have a preference for arithmetic approaches and experience numerous difficulties in adopting algebraic strategies, including constructing equations from word problems, interpreting algebraic expressions, rewriting algebraic expressions, and simplifying algebraic expressions. However, Swafford and Langrall (2000) found that prior to instruction in algebra, students could construct equations representing problem situations, although many had difficulty using these equations to solve the problems.

Researchers studying students making the transition from arithmetic to algebraic strategies have identified two main types of arithmetic strategies and one algebraic strategy (Johanning, 2004; Stacey & MacGregor, 2000; Van Dooren, 2002; Van Dooren, Verschaffel, & Onghena 2003). The first arithmetic strategy uses the mathematical structure in the problem to work toward an answer. Sometimes this approach is called "unwinding" or "working backward," because students take known values and work back toward the unknown value using information from the problem. The other arithmetic strategy is a guess-and-check strategy in which students select numbers they believe may be the correct answer and check them to see if they meet the requirements of the problem. Selection of guesses can range from being apparently random to being highly systematic. Van Dooren, Verschaffel, and Onghena (2003) categorized a strategy as algebraic when a significant part of the solution process consists of manipulating symbolic expressions containing unknown values, while the concrete meaning of these manipulations in relation to the problem context is temporarily suspended. This is in contrast to arithmetic strategies that consist of consecutively performing operations on known numbers, while their meaning remains invariably connected to the original problem context.

Students' selection of the strategies they use is a complex process, influenced by a number of factors, and leads to a variety of results. Lannin, Barker, and Townsend (2006) noted factors influencing strategy choice, such as the mathematical structure and specific values in the problem, the social influences of teacher and students, prior strategies students have used, and visual images students generate for the problem. This variety of influences results in different strategy choices. For example, Johanning (2004) studied the strategies of 31 sixth, seventh, and eighth graders before they had formally studied algebra and found that systematic guess and check was the most common and the most successful of arithmetic approaches. She concluded that the successful arithmetic approaches attended to structural relationships and meaning of information in problem. Although encouraging students to choose to use powerful algebra techniques is often seen as a goal in secondary mathematics, for some problems, arithmetic approaches are more efficient (Van Amerom, 2003). Ultimately, Van Dooren (2002) concluded that students needed to be flexible in their strategy use, drawing on their understanding of the problem and available strategies, whether they are algebraic or arithmetic.

Research Questions

In an effort to identify and study strategies secondary mathematics students use to solve problems, we gave students a problem (see Figure 1) to solve that could be done arithmetically or algebraically. We used the following questions to guide our investigation of student responses:

- How well would students do on the Apples problem?
- What strategies would students use to solve the problem and which would be most popular?
- Would the most popular strategy be the most likely strategy to produce a correct solution?
- Would students use the same strategy to solve the same problem over three years?

John bought a certain number of apples at 30 cents each and he had $3 left. If instead, apples were 40 cents each, he would have been short $1. How many apples did he buy? Show your work.

Figure 1. Problem adapted from an item in the Singapore curriculum and given to 8th-, 9th-, and 10th-graders.

Sample

In this paper, we report how several thousand 8th-, 9th-, and 10th-graders solved the Apples problem shown in Figure 1. The problem was designed to assess students' ability to solve a problem using algebraic reasoning and was included in tests given to students in three consecutive years. Overall, these tests were designed to assess students' reasoning and justification abilities. We examined the strategies that 2,508 students used in Year 1, 2,961 students used in Year 2, and 2,356 students used in Year 3 as part of a larger project[1] that involved students and their respective teachers within schools in five states. These students were from a variety of schools, taught by many different teachers, and used several different textbooks. Therefore, we do not attribute a preferred strategy or a level of performance to any specific school, teacher, or textbook.

Results

Piloting the Problem

We anticipated three different successful approaches that reflect the three strategies noted in the prior research. We expected some students to write two different linear equations representing the situation with the number of apples John bought as the single unknown and then solve the system of equations. We anticipated that other students would guess the number of apples John bought and check whether it matched the information in the problem. This strategy could range from a highly systematized approach where trials would be organized in a table to a random and somewhat unorganized guess-and-check approach. The third expected strategy reflected what we called an arithmetic approach. This strategy would include finding the differences between money left over and the costs per apple, and then using the quotient to find the number of apples purchased.

The anticipated strategies were used to classify students' responses. The reliability of the process was established through double coding, resulting in inter-rater reliability percents between 78 and 100%. More details have been reported elsewhere (Chávez, Grouws, Tarr, Ross, & McNaught, 2009). The student work was used to classify the strategy, regardless of whether students were successful at showing complete work and arriving at the correct answer. To account for other ways to solve the problem, we included *other* to denote any strategy that was not one of the three anticipated or when we could not determine what strategy the student was using. We reported students who did not make any marks on the paper separately.

Student Performance

For the problem, we scored student work and answers separately. Answers were scored as correct or incorrect. Over three years, about one-fifth of the students were able to provide a correct answer. The percent of students providing a correct answer increased each year, from 14.3% in Year 1, to 22.7% in Year 2, and to 29.0% in Year 3.

Work was scored from zero to three points. Zero points indicated no meaningful work. One and two points were awarded for different levels of partially correct reasoning demonstrated by students. Full credit was given to students demonstrating full understanding of the problem, no matter what strategy they used. Over three years, with regard to their work, 21% of the students received full credit, and about 11% received partial credit. Almost 10% of the students did not attempt the problem.

Strategies Students Used

A summary of the student strategy choices on the problem is shown in Figure 2. It summarizes results from the three years, and shows that the percentage of students using each of the various strategies remained relatively stable. An exception is a larger percentage of students who used the *equation* strategy, and fewer students were coded as *other*. The increasing percentage of students using the equation strategy likely reflects the growing attention to algebra experienced by the students over the three-year study. Of the anticipated strategies, the *table/guess and check* was the most popular strategy each year. Fewer students used the *equation* strategy, and the least number of students used the *arithmetic* strategy.

In the first two years, the majority of students' strategies were coded as *other*, and in the third year, nearly half of

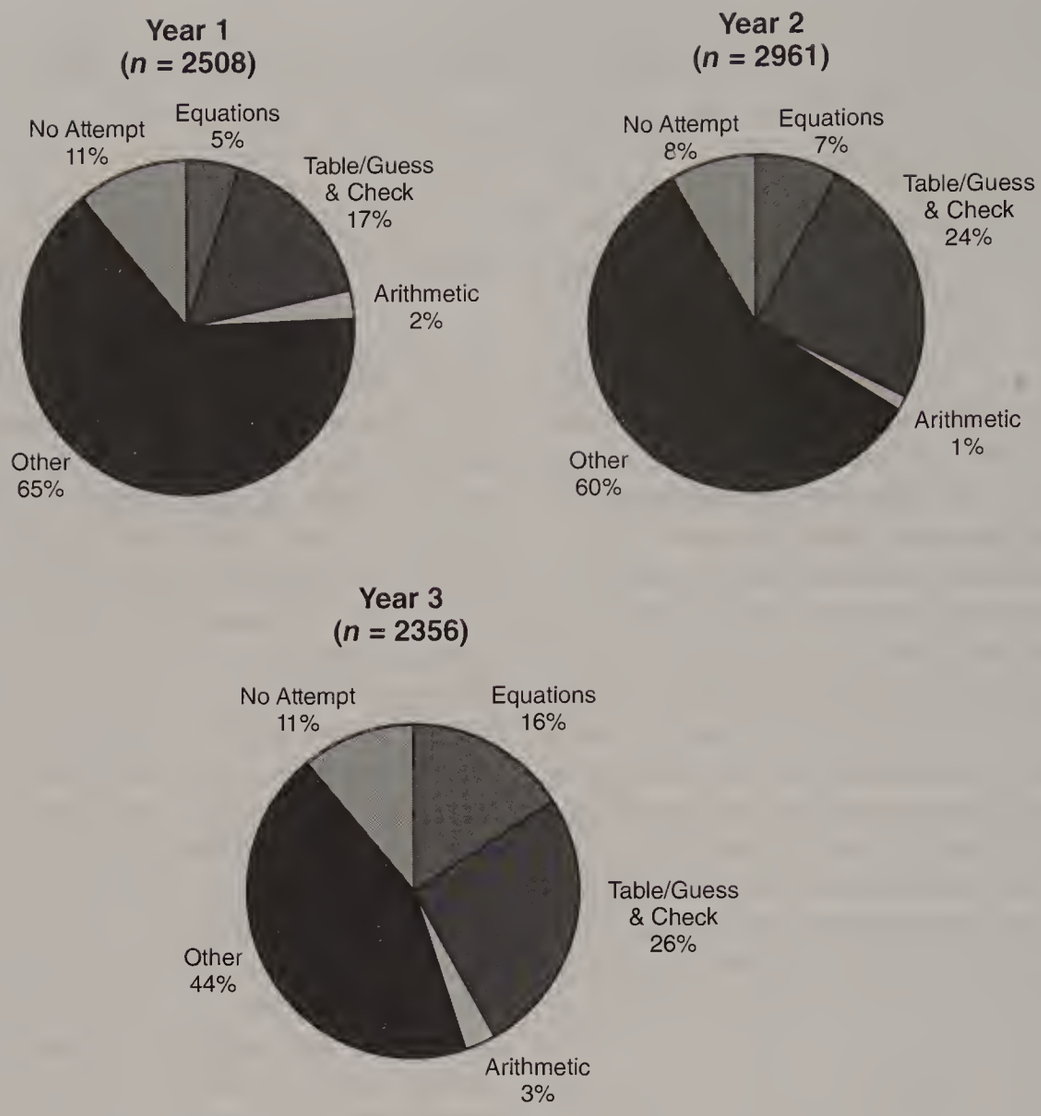

Figure 2. Student strategies on the Apples problem.

students' strategies were coded as *other*. We were interested in seeing strategies that students used beyond the ones we anticipated, so we examined these *other* responses very carefully. We found very few reflected meaningful work for the problem, and no pattern of other significant strategies emerged.

About 90% of the students with strategies coded as *other* did not receive any credit for either their work or answer. These responses, which generally did not represent a strategy for working toward a solution of the problem, can be further classified as follows. Some students made marks on the page that were unintelligible or their writing did not appear to relate to the problem. For example, some students wrote only a question mark on the page, apparently as an indication that they did not have any idea how to approach the problem. Other students wrote only an incorrect answer on the answer line, with no indication of how they arrived at their answer. Some students provided comments or questions that were related to the problem but not indicative of any strategy used to solve the problem. For example, numerous students only wrote the claim that the problem could not be solved without knowing how much money John started with. Some students copied numbers from the problem, but did not indicate use of those numbers in any way. For example, a student wrote "30¢ = 3$ left, 40¢ = -1$ left, 4 apples." Some students used numbers from the problem to make calculations, but not in ways that reflected the meaning of the problem or that would lead them to a correct solution. For example, one student wrote "$\frac{30}{40} = \frac{3}{1} = \frac{30}{12} = 2.5$." One common response of this type was to claim that since $0.30 × 10 was $3.00, then John must have purchased 10 apples. Although these students demonstrate an understanding of how to calculate a total price for a given number of apples, they do not show understanding of what

the $3 means in the problem, how to use the other information, or how to pursue a solution to the problem. Analysis of these responses suggests that essentially no consequential strategies were demonstrated in these nearly 4,000 responses.

Not all strategies coded as *other* were related to incorrect answers. Three hundred sixty-five students with strategies coded as *other* received credit for a correct answer. Of these, 243 responses did not receive any credit for their work, either because students did not show any work or their work did not show any intelligible strategy for reaching the solution they provided. The rest of the responses, totaling 122 over three years, received partial or full credit for their work, thus providing strategy choices that could be examined. Most of the strategies used in these cases were modifications of the three anticipated strategies included in the rubric. For example, some students indicated a guess that John had $15, then checked that the claims in the problem would be true, and concluded that he must have purchased 40 apples. Other students modified the *arithmetic* strategy. For example, one student realized the difference in cost for every five apples was $0.50 and that a total difference of $4 was needed. The student divided to determine that eight differences were needed, and thus John purchased 40 apples. This response was given full credit for the work and coded as an *other* strategy. A number of students used a modification of the *equation* strategy by creating a system of equations, graphing the equations either by hand or with a graphing calculator, and found their solution at the key point in the graph. These responses are subtly different from the anticipated strategies but did not represent a single strategy that required a different code. Ultimately, although a small percent of the responses coded as *other* demonstrated meaningful strategies, our analysis suggests that nearly all responses classified as *other* were, in effect, nonstrategies or invalid responses.

Successful Strategies

We investigated the relative success of different strategies by examining which of the three expected strategies had the correct answer, represented by the right-hand columns in Figure 3. In Year 1, students using the *table/guess and check* strategy had the highest percent of correct answers, about 50%. In Years 2 and 3, students using the *arithmetic* strategy had a higher rate of success, about 80%, but only about 1% of the students in Year 2 and about 3% of the students in Year 3 used this strategy. In Year 3 and overall, the *equation* strategy led to the least percentage of correct answers. The largest difference was between students who used one of the anticipated strategies and students whose strategies were coded as *other*. Altogether, about one-half of the students who used each of the anticipated strategies arrived at the correct answer. In contrast, only about 8% of the students coded as *other* provided a correct answer to the problem.

We also examined which strategies were associated with higher credit for the work on this problem, represented by the left-hand columns in Figure 3. Again, overall, the clearest difference was between students' with strategies coded as *other*, of whom less than 3% earned full credit for their work, and students who used an anticipated strategy, of whom over half earned full credit. Students who used the *table/guess and check* strategy tended to earn full credit on the work more often than the two other anticipated strategies, except in the second year when, the *equation* strategy led to the highest percent of students (about two-thirds) earning full credit for their work. However, a higher percent (nearly 11%) of the students who used the *equation* strategy also received no credit for their work when compared with students using the other two strategies. Students who used the *arithmetic* strategy most often earned partial credit for their work.

Strategy Choices of Students

We followed a subgroup of these students for three years and examined whether students that used a given strategy in Year 1 tended to use it again in Years 2 and 3 and how their strategy choice affected their success in subsequent years. For this analysis, we examined responses for only the 997 students who took the Apples problem all three years. Within this subgroup, the percent of students that provided the correct answer in each year were as follows: in Year 1, 20.5%; in Year 2, 32.3%; and in Year 3, 30.1%.

In Table 1 we report the 20 most common sequences of strategies coded for these students. One clear trend was for students to use the same strategy over all three years. About one-third of students were coded as using the same strategy all three years. However, being coded as *other* for all three years happened three times as often as the next most common sequence. Essentially, many students who did not show a meaningful strategy in the first year did not improve in the second or third year. Besides this group, using *table/guess and check* and *equations* all three years were also among the most common sequences.

About two-thirds of the students switched strategies over the three years. The most popular strategy students moved toward was *table/guess and check*, which about 37% of the students switched to at some point. For example, the 219 students in the second, third, and fourth

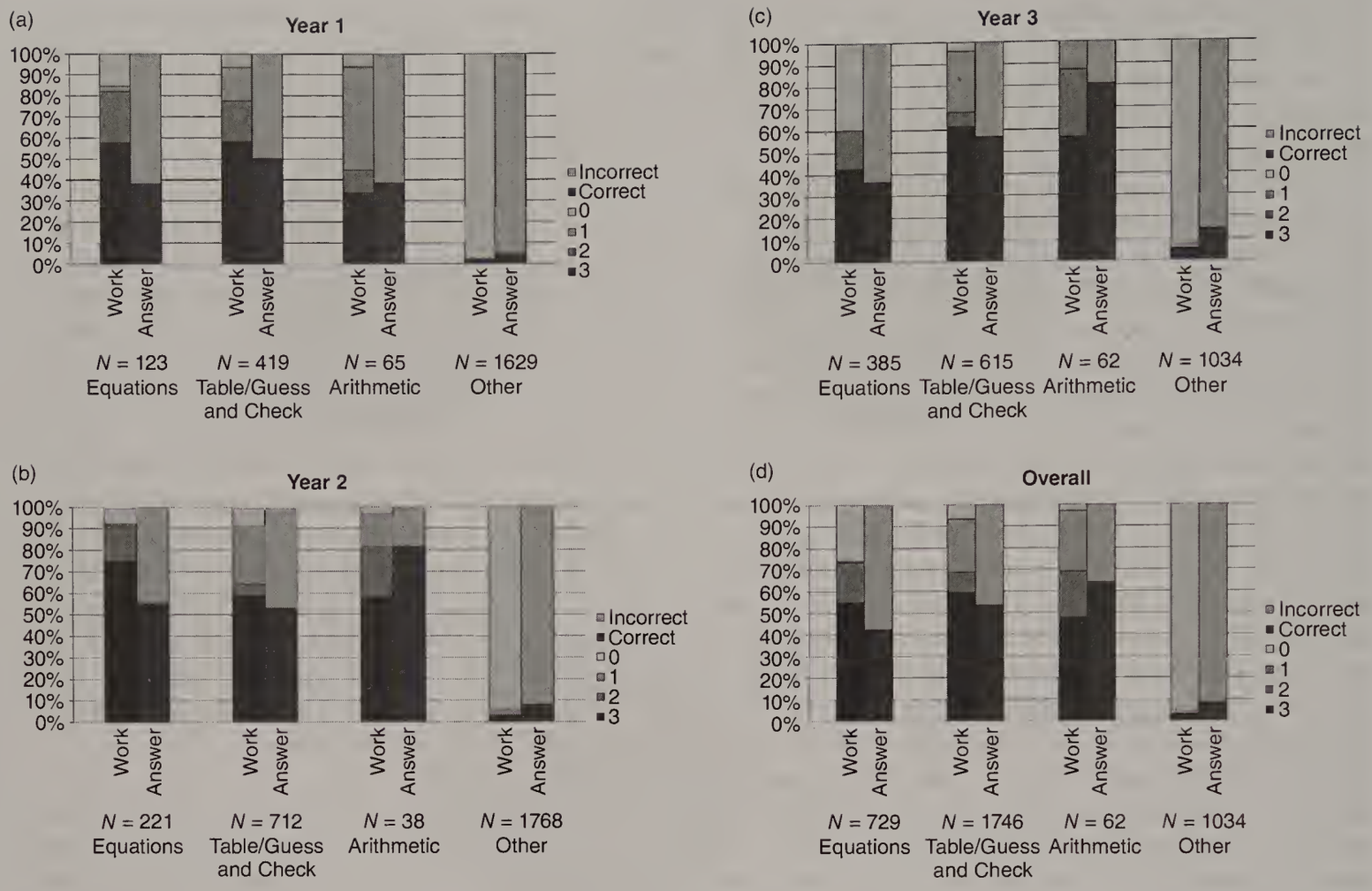

Figure 3. a. Student results on work and answer by strategy, Year 1; b. Student results on work and answer by strategy, Year 2; c. Student results on work and answer by strategy, Year 3; d. Student results on work and answer by strategy, overall.

sequences listed in Table 1 switched from *other* to *table/guess and check*. Notice that not all of these students stayed with the *table/guess and check* strategy. For example, the students in the fourth row switched to this strategy in Year 2, but back to *other* in Year 3. Fewer students switched to *equations* and *arithmetic* over the course of the three years, with less than 15% and 4% of students switching to these, respectively.

Another trend evident from this table and supported by the data presented earlier on student strategy choice each year is the common occurrence of *other* and *table/guess and check*. The top seven sequences, representing over half of the students, included only these two codes over all three years. In contrast, the scarcity of the *arithmetic* strategy is evident in that it is included in none of the most common sequences.

As explained previously, student strategies coded as *other* were generally meaningless. Many students had their strategy coded as *other* or did not attempt the problem in at least one of the three years. Only 139 students used the three anticipated strategies exclusively over the three years. Among these students, using *table/guess and check* at some point in the three years was again the most prevalent trend; about half used this strategy all three years. The most common strategy to which these students switched was *equations*; about one out of four students did so. However, nearly as many students switched to *table/guess and check*. Only 18 students switched to *arithmetic* at any point in the three years.

How did students' strategy selection impact their success on the item? The most striking trend was that when students used one of the three anticipated strategies, even if they switched between them, their performance was better than students who always attempted the problem but were coded as *other* at least once. However, overall performance of students who used only a combination of *equations*, *table/guess and check*, or *arithmetic* did not improve over three years.

Within the group of students who used only an anticipated strategy, the students who used the same strategy all

Table 1
The 20 Most Common Student Strategy Sequences

	Year 1 Strategy	Year 2 Strategy	Year 3 Strategy	*N*	% of All Students
1.	Other	Other	Other	217	21.8
2.	Other	Other	Tbl/g&chk	75	7.5
3.	Other	Tbl/g&chk	Tbl/g&chk	72	7.2
4.	Other	Tbl/g&chk	Other	72	7.2
5.	Tbl/g&chk	Tbl/g&chk	Tbl/g&chk	61	6.1
6.	Tbl/g&chk	Tbl/g&chk	Other	39	3.9
7.	Tbl/g&chk	Other	Tbl/g&chk	38	3.8
8.	Other	Other	Equations	38	3.8
9.	Other	Other	No attempt	38	3.8
10.	Tbl/g&chk	Other	Other	34	3.4
11.	Other	No attempt	Other	17	1.7
12.	No attempt	Other	Other	16	1.6
13.	Other	Tbl/g&chk	Equations	15	1.5
14.	Equations	Equations	Equations	14	1.4
15.	No attempt	Other	No attempt	12	1.2
16.	Other	Equations	Other	11	1.1
17.	No attempt	Tbl/g&chk	Tbl/g&chk	11	1.1
18.	Tbl/g&chk	Equations	Equations	10	1.0
19.	No attempt	Other	Tbl/g&chk	10	1.0
20.	Other	Tbl/g&chk	No attempt	9	0.9
			Total:	809	81.1

Tbl/g&chk = table/guess and check.

three years tended to perform better than the remaining students. Students who used only one strategy, whether it was *equations*, *table/guess and check*, or *arithmetic*, tended to perform similarly. Their performance did not improve over the course of three years.

Students who switched strategies demonstrated poorer performance over the course of three years if they switched to *other* at some point. Performance of students who switched to one of the three anticipated strategies tended to improve over the course of the three years. Students who switched to *arithmetic* performed better than those who switched to *equations* or *table/guess and check*.

Discussion

The results presented above lead to the following conclusions in relation to each of the questions posed at the beginning of the article.

How Well Did Students Do? Overall, students did poorly, with only about one in five students answering the problem correctly or earning full credit for their work. Algebraic concepts and skills that students could use to solve this problem are a focus of typical curricula for junior and senior high school students, and we expected better initial performance, and that performance would improve after several additional years of mathematics.

What Strategies Did Students Use and Which Was Most Popular? The most popular strategy was *other*. Typically, strategies coded as *other* included some written response, but very rarely provided any meaningful work. It was disheartening to see so many students' strategies coded as *other*, which generally did not provide any insight into student understanding of the problem. Why did so few students use an effective strategy? For those students who used a meaningful strategy, how did they choose it? One limitation of the study was that information on the reasons students chose specific strategies was not gathered; thus we can only hypothesize about why students responded as they did.

Nevertheless, it is clear that many students did not effectively select and use strategies for this problem. We need to seek ways to help students find meaning in a problem and represent that meaning mathematically. One key to this is providing students opportunities to explore novel problems and work to make sense of them. Teachers in the United States are often tempted to step in and simplify problems at the first sign of students struggling (Hiebert et al., 2005). Hiebert and Grouws (2007) reported that research consistently shows students learn better when they have a chance to wrestle with challenging problems. A similar attitude was reflected by Warren Colburn (1912) when he wrote, "The learner should never be told directly how to perform an operation . . . much less should he have the operation performed for him. I know it is generally much easier for the teacher, when a scholar finds a question a little too difficult and comes for assistance, either to solve the question for him, or tell him how to do it" (p. 471). If students are to make meaning of problems like the Apples problem, we must provide students opportunities to engage in problems and then resist stepping in too early and removing any challenges the problem presents.

Of the three anticipated strategies, *table/guess and check* was the most popular strategy. This is consistent with an examination of the strategies used on similar algebra problems in Singapore (Ng & Lee, 2009; Wong & Lee, 2009) and Stacey and MacGregor's (2000) findings that students' significant arithmetic background urges them away from algebraic solution methods. While the *table/guess-and-check* strategy can be used to reach the correct answer, it is generally less efficient than the *equations* or *arithmetic* strategies. Students could make many guesses or long tables before arriving at the answer. The *table/guess and check* strategy lends itself well to technology and the use of a spreadsheet where patterns will emerge. Furthermore, this approach is accessible to students before they study algebra. Despite a small increase in the number of students using the *equation* strategy in Year 3, the *table/guess and check* strategy was still predominant. We hypothesized that after three years of secondary mathematics instruction, more students would have progressed toward using strategies emphasized in the secondary curriculum or more efficient strategies such as the *arithmetic* approach.

How can we help students move toward more efficient strategy choices? One way is to use problems like the Apples problem to show students how a *table/guess and check* strategy is inefficient, but can lead to forming equations to solve the problem (Cuoco, 2008). For example, with the Apples problem, the teacher could have students make several guesses and record the checks. Organizing this information to highlight the similar structure and varying quantities in guesses could help students move from a series of guesses toward a system of equations that students could use to solve the problem. Repeated opportunities to use this approach would help students move from relying on guessing and checking toward using more algebraic approaches. This approach builds on students' understanding as a natural bridge to more powerful, abstract strategies as well as providing motivation for use of such strategies as students realize how much work can be involved in guessing and checking answers.

Was Students' Most Popular Strategy the Most Likely Strategy to Produce a Correct Solution? The *other* strategy was most likely to produce an incorrect answer. The *arithmetic* strategy was most likely to produce a correct answer, but it was by far the least utilized strategy. Both the *equations* and *table/guess and check* strategies led to a correct answer only about half the time, with the *equation* strategy actually leading to a smaller percentage of correct answers than *table/guess and check*. In secondary mathematics courses, students are apparently learning that modeling problem situations with equations is a good strategy, but are not gaining enough facility with the strategy to use it to arrive at a correct answer.

Regardless of the strategy chosen, these results suggest that students need to monitor their strategy choice and reflect on the reasonableness of their answer. When they recognize an approach is not leading them to a reasonable answer, they should seek to find errors or switch to a different strategy. Sharing various strategies students used for solving a given problem can be enlightening and helpful. As teachers we can also draw students' explicit attention to the need to monitor their strategy choice and to reflect on the reasonableness of their answers.

Students using the *table/guess and check* strategy tended to earn full credit for their work more often than other strategies. These students appeared to understand the strategy well enough to demonstrate a number of guesses at the

solution and accurate checks of these guesses or to build an accurate table to track potential answers and check their answers. In contrast, students using the *equation* strategy were more likely to receive no credit for their work. This suggests that some students using this strategy might have thought that they were expected to try to use algebraic equations to solve problems like the Apples problem. Therefore, they attempted to write equations but apparently did not know how to create equations that accurately depicted the problem.

What Strategy Choices Did Students Make Over Three Years? The short answer to this question is they made nearly every conceivable choice. Dominant trends involved *other* and *table/guess and check*. When students switched strategies, more than half the time they switched to one of these two strategies. These students had taken three years of secondary mathematics courses, and considering the power of the *equations* strategies and the typical goal of secondary mathematics to enable students to use algebraic equations to solve problems, we anticipated a clear migration toward using *equations* in Year 3. However, few students switched to the *equations* strategy during the three years. These results indicate that students are not making better strategy choices after two additional secondary mathematics courses.

How Did Strategy Choices Impact Performance? It was not surprising to see that students with strategies coded as *other*, whether they switched to this or maintained it, tended to have lower performance, because strategies coded *other* were generally invalid or incorrect. Of the students who used only the anticipated strategies, those who did not switch performed better than those who switched strategies at some point. However, the performance of students who used the same strategy tended not to improve over the three years. It is troubling that, for example, students who used *equations* in Year 1 would not show improved performance over two additional years of secondary mathematics courses. Students who switched to one of the three anticipated strategies showed improved performance, especially those who switched to *arithmetic*. However, this was the least common change of strategy. Additionally, it is not surprising that students who switched from using a meaningless strategy coded as *other* to an intelligible mathematical strategy would improve in demonstrating meaningful work and answering the question correctly.

Conclusion

This paper examined the performance of several thousand students on a single problem. The problem was not a routine problem, yet one that could be solved intuitively or more formally with equations. While our three anticipated solutions—*arithmetic*, *table/guess and check*, *equations*—were used by the students, the majority of the solutions were more closely associated with invalid and meaningless strategies. This occurred despite the fact that all of these students had studied up to three years of high school mathematics.

Considerable time and effort is spent in high school working to provide students with the algebraic tools to solve problems. Our findings suggest that current approaches are not equipping students well. Research has indicated that students will not learn what they do not have opportunities to learn and that teachers need to pay explicit attention to helping students develop conceptual understanding (Hiebert & Grouws, 2007). Teachers need to give explicit attention to strategies and students' strategy choice. Instruction should be aimed at developing understanding and encouraging students to move toward more powerful and efficient strategies. Considering that so much is invested in helping students gain understanding of algebraic strategies, teachers should especially focus on helping students understand how to transition into effective use of these strategies.

Our findings are in line with other studies that have found students' transition into using algebraic solutions methods problematic (Herscovics & Linchevski, 1994; Stacey & MacGregor, 2000; Van Amerom, 2003; Van Dooren, 2002; Warren, 2003). In addition, we have demonstrated that even after several years of secondary mathematics instruction, many students are not using effective strategies to solve problems. It is worth examining whether this situation is the result of the mathematics curriculum these students are experiencing, the classroom environment, and the pedagogical approaches the students are experiencing. More research is needed to address these questions.

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Enriching Science and Math Through Engineering

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This case study reviewed the collaborative efforts of university engineers, teacher educators, and middle school teachers to advance sixth- and seventh-grade students' learning through a series of project-based engineering activities. This two-year project enriched regular school curricula by introducing real-world applications of science and mathematics concepts that expanded opportunities for creativity and problem-solving, introduced problem-based learning, and provided after-school programming (for girls only) led by engineering students from the local university. This engineering education initiative showed significant impact on students' (1) confidence in science and mathematics; (2) effort toward science and mathematics; (3) awareness of engineering; and (4) interest in engineering as a potential career. With regard to gender, there were no significant differences between boys' and girls' responses. The girls' confidence in their own skills and potential, however, was significantly more positive than the boys' confidence in the girls. These results gave rise to new questions regarding mentor/mentee relationships and the overall effect of "girls only" mentoring.

Introduction

In this case study research, a group of middle school teachers and administrators partnered with university engineers and teacher educators to advance sixth- and seventh-grade students' learning through a series of project-based engineering activities. This two-year project was designed to enrich regular school curricula by introducing problem-based learning that purposefully integrated engineering with science and mathematics. We wondered if we could positively impact students' interests and attitudes in science and mathematics and encourage engineering as a career option through these combined efforts.

Literature Review

We initiated this research with enthusiasm for learning how engineering lessons and activities might increase middle schoolers' motivation and interest in science, mathematics, and engineering careers. It is well documented that middle schoolers have already begun to develop dispositions toward mathematics, science, and engineering (Eccles & Midgley, 1989; Mooney & Laubach, 2002; Ryan & Patrick, 2001). We knew too, that in this period of early adolescence, students either begin to develop strong academic habits or they begin to struggle in school (Ryan & Patrick).

Developing Confidence and Positive Attitudes

Some students, at or near middle school age, develop anxiety or aversion to mathematics, believing that only certain students can be good at mathematics and that no amount of effort can make a difference for those who are not good at mathematics (Schoenfeld, 1992; Stodolsky, Salk, & Glaessner, 1991). Students' developing notions that their own difficulties with science or mathematics are due to a lack of ability undermine their motivation and can lead to anxiety (Ryan & Patrick, 2001). Supportive teachers can help reduce anxiety and successfully motivate middle school students to learn mathematics and science. Teachers' encouragement and support can lead to students' increased interest and enjoyment in school work, enhanced academic self-image, and greater expectancies for school success (Ryan & Patrick).

Integrated Learning

The construct of integrated teaching and learning arises from the constructivist learning theory (Bruner, 1977; Dewey, 1966; Piaget, 1973), which suggests that linked or connected learning experiences enhance the learning overall. This teaching for understanding involves teachers as facilitators, students as active learners, and construction of knowledge rather than simple absorption of facts (Berlin, 1989, 1990; Furner & Kumar, 2007; McKinney, 1993). Mathematics can enable students to achieve a deeper understanding of science concepts by providing ways to quantify

and explain science relationships. Science activities, illustrating mathematics concepts, can provide relevancy and motivation for learning mathematics (Berlin, 1994; McBride & Silverman, 1991). Further, Berlin (1994) found that students greatly enjoy integrated lessons but that teachers, administrators, and parents worry whether students are really learning or simply playing. Barab (1999) found that high school students showed higher interest in integrated classroom activities, and their problem-solving, cooperative group skills increased. Jacobs (1989) reported links between integrated curriculum, higher attendance, and better attitudes toward school.

Advantages of Engineering Curricula

Engineering curricula provide a vehicle for integrating science and mathematics—and a context for the relevance and application of science and mathematics (Sullivan et al., 2005). Engineering education bridges classroom lessons to real-world experiences through concrete applications (Iversen, Kalyandurg, & de Lapeyrouse, n.d.). Given that women and minority populations are underrepresented in engineering professions and that engineering degree enrollments are flat, there is grave concern for the general public's limited awareness of engineers and their roles in creating new technologies that improve our quality of life (Sullivan et al.). Certainly, engineering education in middle school can serve to introduce engineering as a viable career option.

Brophy, Klein, Portsmore, and Rogers (2008) reviewed 25 promising models of P-12 engineering education. They found that engineering education can be integrated into curricula to increase a wide range of knowledge and skills in science, technology, engineering, and mathematics (STEM). They raised concern regarding classroom teachers' knowledge of engineering and institutional challenges such as high-stakes assessments.

Encouraging Girls in Science, Mathematics, and Engineering

Although women make up nearly half of the U.S. workforce, they make up only 26% of the STEM workforce (Halpern et al., 2007). Research and intervention projects since the American Association of University Women (AAUW) Educational Foundation's (1992) report *How Schools Shortchange Girls* have indicated patterns of progress in improved instruction and innovative learning opportunities for girls (AAUW, 2004). Still, many bright students, particularly women and minorities, choose not to pursue engineering careers (Mooney & Laubach, 2002).

Recent researchers point to some new understandings about gender and STEM. Fouad (2008) tracked middle school girls through high school and college. She reported that self-confidence instilled by parents and teachers had greater impact on girls' learning in science and mathematics than girls' initial interests. Dweck (2007) reported on interventions that shrink gender differences in mathematics. She found that teachers' messages about developing ones' intellectual ability (to counter students' perception of intellectual ability as a gift) not only served to alleviate girls' vulnerability but increased student performance overall.

In summary, research suggests the importance of encouraging middle schoolers' (boys' and girls') confidence and attitudes toward science and mathematics. Integrated science and mathematics instruction, combining both concrete and abstract learning opportunities, can provide a motivational context for learning. Engineering curricula, linked to appropriately integrated science and mathematics content, both motivates student learning and introduces career options. Girls at the middle level are in particular need of STEM learning support.

Methodology

In this study, we explored the overall impact of a two-year engineering enrichment project in a middle school. Students' possible involvement included *Get a Grip* lessons during a regular school day (boys and girls) and an after-school mentoring (girls only). Our specific questions included the following:

1. Did the *Get a Grip* integrated engineering curriculum or after-school mentoring influence middle level students' ideas and attitudes toward science, mathematics, and engineering?
2. Did the project's effect differ between boys and girls?

Research Design

This research followed sequential explanatory mixed methods design (Creswell & Plano-Clark, 2007) with a greater focus on the quantitative data (QUAN → qual). According to this design, researchers gathered qualitative data to explain or elaborate on the quantitative findings collected in the first phase of the study. The quantitative data were expected to provide generalizable results, while the qualitative data would help describe our quantitative results.

First, the quantitative survey instruments collected mathematics (Middle School Mathematics Attitude Survey [MSMAS]) and science (Middle School Science Attitude Survey [MSSAS]) attitudes of sixth- and seventh-grade students. These pre/postsurveys measured changes in students' mathematics and science confidence, value of mathematics and science, and knowledge/interest in engineering over the two-year project.

In the qualitative phase, an interview protocol prompted the lead teachers to describe their experiences and observations relative to the *Get a Grip* lessons and after-school mentoring program. The protocol encouraged lead teachers to reflect on notable changes in students' behaviors (both in the classroom and in after-school mentoring) and/or attitudes toward science or mathematics.

Research Participants

Participants included sixth- and seventh-grade students (N = 1,287) and 12 teachers (representing three core teaching teams) from an Oklahoma middle school. There were approximately 757 students (78% Caucasian, 9% African American, 3% Asian, 3% Hispanic, and 6% Native American) enrolled in this middle school during each year of this project, and 32% of the student body were eligible for free and reduced lunches. Eighty-one percent of the sixth-grade students and 90% of the seventh-grade students scored at the satisfactory level or above on the state assessments in mathematics in 2006–2007 (science exams are not yet required). In 2007, nearly 40% of seventh graders scored at the advanced level in mathematics compared with 22% statewide.

All 12 of the sixth- and seventh-grade teachers (language arts, social studies, mathematics, and science) led *Get a Grip* lesson activities related to their own core content. Two science teachers from this group (one sixth-grade teacher and one seventh-grade teacher) led the after-school mentoring program along with university faculty and students. (These two teachers are identified throughout the remainder of this report as the *lead teachers*.) All 12 project teachers followed standards-based curriculum and regularly participated in district-wide professional development days (five per year). The lead teachers (one early-career and one experienced teacher) also attend annual state and national science conferences and help lead engineering summer camps for middle level students.

Treatment

An interdisciplinary research group (consisting of an engineering professor, female engineering students, science education faculty, and mathematics education faculty at a large Oklahoma university) organized an engineering enrichment project to positively affect students' attitudes toward science, mathematics, and engineering career awareness. In order to accomplish these goals, the research team implemented two related interventions over two years. Table 1 lists the total interventions. The control group did not participate in any of these engineering enrichment activities.

Table 1
Assigned Abbreviations for the Possible Engineering Interventions

Intervention	Abbreviation
Get a Grip activity in the classroom, one year	ENG^1
Get a Grip activity in the classroom, two years	ENG^2
Get a Grip activity in the classroom and after-school mentoring	ENG^M

In the Curriculum Integration Project, core teams taught an integrated thematic unit entitled *Get a Grip* (aligned with both the *National Science Education Standards* (National Research Council, 1996) and the *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993) and originally developed at Northwestern University and funded by the National Science Foundation). *Get a Grip* (Olds, Harrell, and Valente, 2006) would familiarize middle school students with engineering as a career and encourage students to make connections between science concepts while completing a real-world engineering task. In this design process, students designed and developed a prosthetic arm (from common materials) to help a 12-year-old Afghani girl eat and carry water from a nearby river to her home. (For more information on the structure of the unit, visit http://www.ideanet.org/get-a-grip/Sci_Scope_Nov_2006_Reprint.pdf.) Most of the eight core *Get a Grip* lessons in the unit correlated with district objectives for language arts, reading, mathematics, and social studies. The unit was taught in May of each year. Some adaptations were introduced in seventh grade as some of the students (ENG^2) had participated in *Get a Grip* during their sixth-grade year (ENG^1).

An after-school mentoring program organized weekly sessions (28 sessions per year) for sixth- and seventh-grade girls (N = 43 including 17 sixth graders and 26 seventh graders). The lead teachers explained that the girls who self-selected into this mentoring group were not the most popular girls or the real social leaders. Rather, it was the girls "who care about their grades and want to do well and they look at this as a way to do that." There were also "quite a few girls" who signed up because "they're not in dance and don't have a lot of money to do all the other things." Female mentors (two lead teachers and 10 engineering students) led activities that introduced engineering design processes and engineering career awareness to the girls. Mentoring activities encouraged the girls to find creative ways to solve real-world problems (such as saving

Table 2
Cronbach's Alpha Scores on Four Subscales of MSMAS and MSSAS

	Confidence		Value		P/T Expect		Gender	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Sixth grade MSMAS	.737	.731	.706	.764	.476	.492	.377	.361
Seventh grade MSMAS	.726	.808	.737	.744	.614	.531	.349	.405
Sixth grade MSSAS	.689	.683	.778	.694	.576	.501	.289	.387
Seventh grade MSSAS	.661	.649	.755	.785	.589	.619	.356	.348

penguins from global warming, managing and improving the water quality of an Amazon community, and designing electric, robotic cars).

Instrumentation

Quantitative survey data from the MSMAS and the MSSAS measured pre/post attitudes and interests of the sixth- and seventh-grade students. Qualitative interview data (transcribed and coded) recorded reflective observations of the lead teachers who helped with after-school mentoring.

The MSMAS and MSSAS survey instruments were developed from the Modified Fennema–Sherman Attitude Survey (Doepken, Lawsky, & Padwa, 1993) and from the Adventure in Engineering Survey (Mooney & Laubach, 2002). The *Fennema–Sherman Attitude Survey* has been used in numerous studies to measure students' attitudes toward mathematics. The original Modified Fennema–Sherman Attitude Survey (Doepken et al.) consisted of four subscales: (1) mathematics confidence; (2) usefulness of mathematics (3) mathematics as a male-dominated subject; and (4) mathematics teacher perceptions. Doepken et al. further modified the survey instrument to measure science attitudes as well. Their Modified Fennema–Sherman Science Attitude Scale consisted of four subscales: (1) science confidence; (2) usefulness of science; (3) science as a male-dominated subject; and (4) science teacher perceptions (Doepken et al.).

Further adaptations of the MSMAS and MSSAS used in this study involved the addition of questions adapted from the *Adventure in Engineering Survey* (Mooney & Laubach, 2002). For example, (1) Girls could be a successful engineer; and (2) I am interested in pursuing a career in engineering. Other questions were developed by the research team. A sample question (developed by the research team) was, "How much effort do you typically put into your work for this mathematics/science class?"

Our MSMAS and the MSSAS instruments consisted of 19 questions in a four-point Likert type format (with A indicating strong agreement with the statement and D indicating strong disagreement) and a 20th question on effort. Three questions were negatively worded questions and reverse coded for analysis. In order to determine the internal consistency of the different subscales within the MSMAS and the MSSAS, a Cronbach's alpha was calculated; however, caution should be used when interpreting the results because some portions were too limited for reliability calculation to be meaningful. Table 2 shows the calculated alpha for each administration of the MSMAS and MSSAS. The instrument was moderately consistent for mathematics and science confidence and value but not consistent for parent/teacher expectations toward mathematics/science or for gender-related questions in mathematics/science.

Data Analysis

To analyze the quantitative data, we ran a Mann–Whitney *U* for independent comparisons and a Wilcoxon-*T* for the paired comparisons. The Mann–Whitney *U* is the nonparametric counterpart of the independent samples *t*-test; the Wilcoxon-*T* is the nonparametric counterpart for paired samples *t*-test. These nonparametric statistical tests are useful if you have a small sample size or a non-normal distribution (Siegel & Castellan, 1988). To determine the probability that they would reject a false null hypothesis, researchers conducted power analyses (Cohen, 1989). The power analyses was conducted using G*Power (Buchner, Erdfelder, & Faul, 2009) and showed a power very close to 1 (.89–.99) for all statistical tests.

Qualitative data (narrative interviews) were transcribed, coded, and analyzed by comparative analysis. Results were organized into themes as guided by this analysis. Verification of truth was ensured by the detailed research plan, triangulation of data, member checks, and detailed descriptions of our experience and understanding (Spradley, 1980). According to Yin (1994, p. 25), such a case study component allows research to "explain causal

links in real-life interventions that are too complex for the survey or experimental strategies."

Research Results

Our results suggest that this engineering project positively influenced middle level students' ideas and attitudes toward science, mathematics, and engineering. The mathematics confidence (p = .000), value of mathematics (p = 000), and advantage of effort put forth in mathematics class (.000) of the students in the experimental group were significantly higher than the control group (see Table 3). The experimental group of sixth graders also indicated enhanced expectations of girls' mathematics ability compared with the control group (p = .000).

The experimental group of sixth and seventh graders demonstrated significantly higher value of science (p = .000) and advantage of putting forth effort in science class (p = .000) than the control group. Although there were no significant differences between the sixth-grade control and experimental groups on the science confidence questions, the science confidence of the seventh graders that participated in the *Get a Grip* intervention was higher (p = .000) than the control group. Both the sixth- and seventh-grade experimental groups identified a significantly increased knowledge of engineering (p = .000) and increased interest in pursuing engineering (p = .000) when compared with the control group (see Table 3).

Narrative data supported these survey results. One lead teacher noted the surprising leadership of a seventh-grade girl who arranged for a community volunteer to bring a prosthetic limb demonstration into the classroom. As this teacher explained, "The seventh graders were the ones who got up and taught the lesson." This teacher is passionate about the meaning this integrated lesson had for her students:

> When they read the story about the boy who lost his leg, and now we're building an arm for a girl who lost hers, I think they see a purpose behind what they're doing. They're trying to do a good job because they know what they do is going to impact somebody's life and I think that's what's missing in schools—especially science classes. They do all these [other] labs and they're not connected to anything that has personal value to them.

Gender and Mathematics Comparisons

There were no significant gender differences in confidence or value of mathematics for sixth-grade participants (see Table 4). However, there were significant gender differences in seventh-grade mathematics confidence. The seventh-grade girls reported higher mathematics confidence than the boys reported after two years of intervention (p = .047).

Table 3
Control Versus Experimental Comparisons

Control–Experimental Comparisons	Sixth Grade		Seventh Grade	
	Z	*P* Value	*Z*	*P* Value
Science confidence	−.229	.819	−10.222	.000*
Value of science	−11.624	.000*	−7.014	.000*
Girls smart enough to do science	−1.145	.252	−4.154	.000*
Effort in science	−6.226	.000*	−9.228	.000*
Mathematics confidence	−14.341	.000*	−10.068	.000*
Value of mathematics	−19.101	.000*	−15.008	.000*
Girls smart enough to do math	−19.482	.000*	−1.110	.267
Effort in mathematics	−5.410	.000*	−3.901	.000*
Know what an engineer is	−13.386	.000*	−13.020	.000*
Interest in engineering as a career	−7.747	.000	−10.160	.000*
I could be a good engineer	−.256	.798	−.990	.322
Girls can be an engineer	−.038	.970	−.340	.734

Note: *indicates significance at p = .000.

Table 4
Gender and Mathematics Comparisons

	Sixth Grade Results				Seventh Grade Results			
	Mean		*Z*	*P* Value	Mean		*Z*	*P* Value
	M	F			M	F		
Mathematics confidence	9.50	3.168	−1.871	.061	12.09	11.87	−1.986	.047*
Value of mathematics	6.19	2.389	−1.244	.214	8.21	8.14	−.344	.731
Teachers interested in mathematics	2.02	.851	−1.063	.288	2.31	2.19	−1.095	.273
Girls just as good as boys at math	1.26	.588	−3.602	.000*	1.39	1.17	−3.628	.000*
Teachers encourage mathematics	2.40	.970	−.580	.562	2.55	2.45	−.647	518
Girls—math popular	3.07	.808	−2.239	.025*	3.31	3.36	−.602	.547
Girls smart enough to do math	1.40	.689	−2.594	.009*	1.40	1.32	−1.967	.049*
Effort in mathematics	4.18	1.01	−1.123	.261	3.68	4.05	−2.810	.005*

Note: *A low score indicates a higher rate of agreement and a higher score indicates a lower rate of agreement.

Table 5
Gender and Science Comparisons

	Sixth Grade Results				Seventh Grade Results			
	Mean		*Z*	*P* Value	Mean		*Z*	*P* Value
	M	F			M	F		
Science confidence	9.15	9.13	−.788	.431	9.89	9.93	−.225	.822
Value of science	8.37	8.36	−.322	.747	8.80	8.79	−.212	.832
Teachers interested in science	2.28	2.44	−1.297	.195	2.28	2.11	−1.683	.092
Girls just as good as boys at science	1.29	1.15	−3.559	.000*	1.48	1.12	−5.495	.000
Teachers encourage science	2.72	2.63	−.649	.516	2.55	2.45	−.920	.358
Girls—science popular	3.23	3.34	−1.472	.141	3.24	3.32	−1.002	.317
Girls smart enough to do science	1.35	1.23	−2.439	.015*	1.60	1.29	−3.677	.000
Effort in science	3.93	4.02	−.493	.622	3.53	4.03	−3.993	.000

Note: *indicates significance at $p = .000$.

There were significant differences regarding perceptions of girls' ability to do well in mathematics (sixth grade, $p = .009$; seventh grade, $p = .049$) and girls' ability to do as well as boys in mathematics ($p = .000$).

Gender and Science Comparisons

These results indicate that there were no significant gender differences in science value or confidence for sixth- or seventh-grade participants (see Table 5). Sixth and seventh grade responses showed a similar pattern (in the gender differences) regarding perceptions of girls' ability to do well in science and girls' ability to do as well as boys in science. The mean scores for all groups were high, but girls were more likely to believe that girls were "just as good" as boys in science (sixth grade, $p = .015$; seventh grade, $p = .000$). Similarly, when asked whether girls could be "just as good" at science as boys and whether girls were "smart enough to do science," the boys and girls' responses were significantly different ($p = .000$). The girls were more likely to agree with this statement than the male participants.

Gender and Engineering Comparisons

There were significant differences in boys' and girls' understanding, interest in engineering careers, and their expected engineering abilities (see Table 6). Boys were

Table 6
Gender and Engineering Comparisons

	Sixth Grade Results				Seventh Grade Results			
	Mean		*Z*	*P* Value	Mean		*Z*	*P* Value
	M	F			M	F		
Know what an engineer is	1.69	2.13	−3.628	.000*	1.84	2.23	−3.459	.001*
Interest in engineering as a career	2.70	3.23	−3.862	.000*	2.82	3.24	−3.802	.000*
I could be a good engineer	1.84	2.14	−3.006	.003*	1.82	2.26	−3.992	.000*
Girls can be an engineer	1.62	1.26	−3.792	.000*	1.60	1.34	−3.624	.000*

Note: *indicates significance at $p = .000$.

Table 7
Gender and Mentoring Comparisons

Girls With Mentoring	Sixth Grade		Seventh Grade	
	Z	*P* Value	*Z*	*P* Value
Mathematics confidence	−.593	.554	−.767	.443
Value of mathematics	−1.369	.171	−.353	.724
Girls smart enough to do math	−.958	.338	.000	1.000
Effort in mathematics	−.071	.943	−.179	.858
Science confidence	−2.242	.025*	−1.745	.081
Value of science	−.568	.570	−2.035	.042*
Girls smart enough to do science	−1.069	.285	−.331	.741
Effort in science	−1.060	.289	−1.068	.286
Know what an engineer is	−.659	.510	−1.367	.172
Interest in engineering as a career	−2.555	.011*	−.736	.462
I could be a good engineer	−.873	.383	−.173	.862
Girls can be an engineer	−1.265	.206	−2.735	.006*

Note: *indicates significance at $p = .000$.

more likely than girls to agree they knew "what an engineer does" (sixth grade, $p = .000$; seventh grade, $p = .001$). Similarly, the boys were more likely than the girls to be interested in pursuing engineering as a career ($p = .000$). The boys were also more likely to agree that they could be a successful engineer (sixth grade, $p = .003$; seventh grade, $p = .000$). Girls were more likely than the boys to agree that "girls could be successful engineer" ($p = .000$).

Gender and Mentoring Comparisons

Sixth-grade girls who participated in the mentoring program had higher science confidence and greater interest in pursuing a career in engineering than those girls who did not participate in the mentoring program (see Table 7). The seventh-grade girls who participated in the mentoring program rated the value of science significantly higher than those girls who did not participate in the after-school mentoring program. There were, however, no significant mathematics attitude differences between the girls who participated in the mentoring program and the girls who did not participate in the program. This implies that the mentoring had more of an impact on science attitudes than mathematics attitudes.

The lead teachers who helped with the after-school mentoring program strongly believed the program made a

difference for girls in a variety of ways. For one thing, this after-school program allowed these teachers to notice the different behaviors between in school and after-school. As one teacher explained,

> These girls are much more quiet in the classroom but, . . . when they get to the after-school program, they're more in a leadership role (they're kind of forced to be in that role) and they've really stepped up to it. They're [creating] their own ideas and I think it helps them realize they do have valid ideas.

Lead teachers also noted that the mentoring girls took on a "team mentality" as girls who shared similar goals. Particularly, among the sixth-grade girls, these teachers observed new confidence in the classroom. It was not so much that these female students began asking higher level questions in class, but rather, they began asking more questions in general and, "I think they feel they can solve problems better now."

One of these lead teachers noted the importance of the college mentors. Asked to think about why the college students were so important—was it that they were engineering students or because they were also girls, this teacher explained,

> I think it's because they're female, college students. I think [our girls] look up to them. I think a lot of [our] girls didn't know what engineering was, so I don't think that was an important factor in whether or not they signed up. I think it was more that they were going to get to work with college girls.

It was the mathematics in these after-school engineering activities that most challenged these girls. As the lead teachers explained, "Math is the one [thing] they're afraid of." Lead teachers noted the girls' reluctance in mathematics. They especially remembered one mentoring session when they were working particularly hard with one group of girls who repeatedly sighed, "The math is just too hard. I just can't do it." With continued coaching, the girls actually solved the problem and one girl burst out enthusiastically, "Wow! We really rocked that math!"

Conclusion

This study provides important results related to improving science and mathematics instruction and engineering career awareness with middle level students. Taken together, this data show that the *Get a Grip* engineering curricula seemed to have a significant impact on all middle school students' (1) confidence in science and mathematics; (2) effort toward mathematics and science; (3) awareness of engineering; and (4) interest in engineering as a potential career. However, for those students who participated in the *Get a Grip* program over two years (ENG^2), there appeared to be no additional benefit except i mathematics confidence. Students who had *Get a Grip* in both sixth and seventh grades demonstrated significantly higher mathematics confidence when compared with the students who only had one experience with *Get a Grip* in seventh grade.

The lead teachers, who had been involved in the program for both years, may have positively influenced these students as they are invested in this engineering initiative and share similar philosophical confidence about how integrated lesson activities increase middle school students' motivation and interests toward science and mathematics, as well as deepen their understanding of science and mathematics concepts.

With regard to gender questions, we noted difference between boys' and girls' ideas about whether girls were "just as good as boys in science and math" and whether girls were "smart enough to do science and mathematics." The girls' belief in their own skills and potential was significantly more positive than the boys' belief in the girls. This seems to point to the fact that *Get a Grip* improved the girls' confidence in themselves, while the boys held to more stereotypical beliefs of girls' abilities. Certainly, the data on the after-school mentoring program for girls pointed to sixth graders' significantly greater science confidence and interest in pursuing an engineering career and seventh graders' significantly greater value of science compared with those sixth and seventh-grade girls who did not participate in the mentoring program.

Discussion

This engineering education initiative resulted in significant impact on students' (1) confidence in science and mathematics; (2) effort toward science and mathematics; (3) awareness of engineering; and (4) interest in engineering as a potential career. With regard to gender, there were no significant differences between boys' and girls' responses. The girls' confidence in their own skills and potential, however, was significantly more positive than the boys' confidence in the girls.

Why were the boys not as confident about the girls' skills and potential in science, mathematics, and engineering? Researchers can explain *what* gender schema children learn from birth, there is much to learn about *how* children learn about gender. We know parents (Jacobs,

Davis-Kean, Bleeker, Eccles, & Malanchuk, 2005) and teachers (Demmert, 2001) have a large impact on children's developing perceptions of self-competence. Fouad (2009) confirmed girls' feelings of self-confidence, instilled by parents and supported by teachers, are a precursor to girls' interests in science and math. This research points to the prevailing gender stereotype held by middle school boys—an influence not referenced in current research literature. While these research results are conclusive about the positive effect on the girls' gender schema, we are concerned that the boys' perceptions may serve to confound the beneficial effects of such an engineering project effort as this. Perhaps we need to give special attention to the boys as well as the girls.

Our mixed methodology research design allowed us to review some interesting differences in the results. For example, there were varied results with the second year data (ENG^2) suggesting that our survey instrument may not have been sensitive enough to gather subtle differences. Certainly, the qualitative data helped to elicit descriptions of the mentored girls' (ENG^m) increased leadership and confidence that was not identified in the survey.

We noted that the mentored girls (ENG^m) showed significantly improved confidence in science—but not so with mathematics confidence. While we have no conclusive explanation for this outcome, we cannot help noting that the two lead teachers were science teachers. Perhaps, too, the after-school mathematics problems were too challenging. As Dweck (2007) reported, girls seem to lose confidence in the face of obstacles. As Dweck explained, girls may have similar abilities as boys, but a difference in coping skills causes girls to wonder about their ability when they are demoralized by challenging problems.

Lastly, we noted two unexpected disappointments with regard to this engineering enrichment project. First, the *Get a Grip* unit was taught in May—after completion of the mandated state tests in April. This was a purposeful decision by the teaching teams. By their reasoning, they needed to spend class time building reading, writing, and mathematics skills that would be tested in late April. Although the teachers found benefit in the *Get a Grip* unit, they clearly did not trust this integrated instruction as adequate preparation for high-stakes tests. Future research needs to address these teachers' concerns about clear incorporation of tested skills as component to integrated instruction.

Get a Grip was but one unit of integrated science and mathematics instruction with an engineering focus. Our original plan included a professional development component that would help all 12 middle school teachers identify the engineering principles and activities inherent in their current curriculum. It was further expected that engineering professors and their graduate students from the local university would provide middle school teachers with training and support in identifying and refining lessons that could become project-based activities and incorporate engineering principles. Unfortunately, this project component was unrealized because of limited professional development funding.

As Brophy et al. (2008) suggested, further research is needed to better understand the policy issues related to teacher professional development and curricular change and that includes engineering education. What are the institutional factors that inhibit the mainstreaming of engineering education and how can they be resolved? How can engineers (with domain knowledge) best help teachers (with pedagogical knowledge) blend engineering education into the traditional school curricula?

Limitations

These mentoring results (ENG^m) could be skewed by self-selection of the participants. As well, given the unequal number of participants in the study groups, one could argue that we would have had more difficulty reaching any data significance. Certainly, more in-depth studies would need to be conducted to determine the actual cause of the elevated beliefs in mathematics effort and "knowledge of an engineer" questions. However, it is highly likely that the students who participated in both interventions had more exposure to engineering concepts, faculty, and mentors, and thus became more aware of engineering careers. We are interested in learning more about the mentoring experience, the motivations of both the college students and the middle school girls, and how one group impacts the other.

To some degree, our study was limited by the instrumentation we chose, the number of after-school mentoring participants, and unexpected limitations in professional development opportunities. We initially chose to use the Modified Fennema–Sherman Attitude Survey (Doepken et al., 1993) and added questions that seemed relative. After conducting a Cronbach's alpha, we realized that our instrument was not consistent for parent/teacher expectations or gender-related questions. Because of this inconsistency, we had to run an analysis on several questions individually that increased the chance of Type 1 errors. We later found the Hirsch, Carpinelli, Kimmel, Rockland, and Bloom, J. (2007), a newly developed survey to measure attitudes toward science, math, and engineering that might be more appropriate for use in future studies.

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Possible Student Justification of Proofs

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The National Council of Teachers of Mathematics calls for an increased emphasis on proof and reasoning in school mathematics curricula. Given such an emphasis, mathematics teachers must be prepared to structure curricular experiences so that students develop an appreciation for both the value of proof and for those strategies that will assist them in developing proving skills. Such an outcome is more likely when the teacher feels secure in his/her own understanding of the concept of "mathematical proof" and understands the ways in which students progress as they take on increasingly more complex mathematical justifications. In this article, a model of mathematical proof, based on Balacheff's Taxonomy of Mathematical Proof, outlining the levels through which students might progress as they develop proving skills is discussed. Specifically, examples of the various ways in which students operating at different levels of skill sophistication could approach three different mathematical proof tasks are presented. By considering proofs under this model, teachers are apt to gain a better understanding of each student's entry skill level and so effectively guide him/her toward successively more sophisticated skill development.

The call for reform in mathematics education is as old as the history of school itself. Over the past three decades, the National Council of Teachers of Mathematics (NCTM) has published several documents (1989, 1991, 1995, 2000) that have stimulated discussion and debate around reform in mathematics education. The NCTM documents remind us that learning mathematics requires more than simply solving exercises by working with symbols, performing desired calculations, and doing routine proofs; rather, learning mathematics is fundamentally about "developing a mathematical view point," "communicating mathematically," "making connections" among mathematical experiences and with "other disciplines," and enhancing "*mathematical reasoning*" (emphasis added; NCTM, 2000, p. 56). The NCTM document of 2000, in particular, emphasizes that the ability to reason is essential to understanding: Proof and reasoning, it suggests, are powerful ways of communicating mathematically, developing insights, and making connections between different mathematical domains and among other subjects. Thus, as teachers work to implement the most current wave of curricular reform in mathematics education, they will need to make proof and reasoning an integral part of the mathematics classroom.

As the NCTM (2000, p. 16) points out, "students learn mathematics through the experiences that teachers provide." In other words, teaching shapes students' understandings of math, their ability to use it to solve problems, and their attitude toward mathematics as a discipline. As well, many researchers point out that the teacher's knowledge and beliefs play a critical role in successfully enacting classroom practices (Fennema & Franke, 1992; Jones, 1997; Thompson, 1984). Teachers must be flexible in their teaching practices, drawing upon their mathematical knowledge appropriately and creatively as they instruct their students (NCTM). Ultimately, they must accept responsibility for establishing and negotiating an acceptable mathematical explanation and justification within the classroom (Yackel & Cobb, 1996). This goal can best be achieved if the teacher feels secure in his/her own understanding of the concept of "mathematical proof" and also has a comprehensive understanding of the way in which students are likely to progress as they become more and more skilled at providing mathematical justifications.

Proof and Curriculum

Gardiner and Moreira (1999, p. 19) claim that "Mathematics is not proof; mathematics is not spotting patterns; mathematics is not calculation. *All are necessary, but none is sufficient.*" Thus, they underscore that one cannot teach mathematics without teaching proof. Furthermore, Wu (1996, p. 224) reminds us that those who want to know what mathematics is all about should learn to write proof. In the same document, he elaborates that it is through mathematics courses that students gets training in logical reasoning and "learn how to distinguish between what is true and what only *seems* [emphasis in original] to be true but is not."

In mathematics education, as Maher and Martino (1996) argue, we are interested ultimately in the student understanding, not just of mathematical principles but of the world itself—and proof and proving offer a means by which teachers might enhance student understanding. Educators, both practicing teachers and educational

researchers, must now address the importance of mathematical proof in the classroom. In fact, Marrades and Gutiérrez (2000, p. 87) insist that helping students "to [come to] a proper understanding of mathematical proof and [so] enhance their proof techniques has become one of the most interesting and difficult research fields in mathematics education."

Although proofs "are the guts of mathematics" (Wu, 1996, p. 222), proofs and proving have played a peripheral role at best in secondary school mathematics education (Knuth, 2002a). Unfortunately, many secondary school students have little experience and even less understanding of proof (Bell, 1976; Chazan, 1993; Hadas, Hershkowitz, & Schwarz, 2000; Senk, 1985). Knuth (2002a, 2002b) observes that teachers tend to introduce students to mathematical proof solely through the vehicle of Euclidean geometry. There is no doubt that proving is a complex task that involves a range of student competencies such as identifying assumptions, isolating given properties and structures and organizing logical arguments. If teachers wish to teach students to think for themselves and not simply fill their minds with facts, then, as Hanna and Jahnke (1993, 1996) stress, it is essential that they place greater emphasis on communication of meaning rather than on formal derivation.

As mentioned before, NCTM (2000) recommends that reasoning and proof become a part of the mathematics curriculum *at all levels* from prekindergarten through grade 12. Given the greater status assigned to proof within the mathematics curriculum, it is essential that teachers plan curricular experiences that can help students develop an appreciation for the value of proof and for those strategies that will assist them in developing proving skills. Mathematics teachers must thoroughly understand the mathematics they are teaching and be able to draw on that knowledge as needed, adapting in appropriate ways to each unfolding moment of instruction. They should be able to analyze critically student work and be able to assess and address the *specific* understandings and abilities of each student as s/he develops the skills involved in constructing mathematical proof (NCTM).

Students' Proof Schemes

Using Balacheff's taxonomy of mathematical proof, one can identify in student examples differing levels of proving skill. In an experimental study of secondary students' conceptions of mathematical proof, Nicolas Balacheff (1988, p. 221) observed students as they were engaged in the process of generating proofs. He noted the various ways in which his participants—28 secondary school students, 13 and 14 years of age—approached a specific mathematical task. He permitted students to work in pairs as they set about completing the following assignment: "*Provide a means of calculating the number of diagonals of a polygon when you know the number of vertices it has.*" After analyzing the results, Balacheff organized student responses into four different ways in which students approached solving the proofs. Furthermore, he argued that these categories represented four increasingly more sophisticated levels of thinking.

The first three levels in Balacheff's proof scheme are all examples of what he called *pragmatic* justifications. In the case of *naïve empiricism*, the first level in Balacheff's taxonomy of proofs, the student arrives at a conclusion concerning the validity of an assertion on the basis of only a small number of particular cases. Balacheff exemplifies this level in his description of the efforts of school students, Pierre and Mathieu. Working together, these boys examined a square, a hexagon, and then an octagon. They concluded that they could arrive at the number of diagonals by dividing the number of vertices by two. In this example of naive empiricism, the boys checked the statement to be proved against a few particular examples and, on this basis, made a universal assertion. With *crucial experiment*—the second level in Balacheff's taxonomy of proofs—the student deals with the question of generalization after generating a claim based on a few examples by examining a case that is not very particular. If the assertion holds in the considered case, the student will conclude that it is valid. Balacheff illustrated crucial experiment by referring to the efforts of Nadine and Elisabeth. These girls chose a polygon of many sides (15) believing that the assertion they came up with could be proved in this instance, and then the assertion would be universally true. In other words, at the level of crucial experiment, the student checks the statement by means of a carefully selected example. A defining characteristic of crucial experiment is the *intentionality* of the student: Deliberate choices must be made (Knuth & Elliot, 1998). Notably, both naïve empiricism and crucial experiment deal with actual actions or showings; the main difference between the two rests with the status of the specific example that is selected to validate the assertion—the example used in crucial experiment proof is often based on carefully selected extreme cases.

In the case of *generic example*—the third level in Balacheff's taxonomy of proofs—the proof rests upon the properties. Here, the example is a generalization of a class, not a specific example. Although the focus is once again a particular case, it is not used as a particular case, but as an

example of a class of objects. The student selects such an example as representative of the class and performs operations/transformations on the example in order to arrive at a justification. Then, the student applies these operations and transformations to the whole class. Balacheff mentions Georges' exploration of the proposition, $f(n) = n^*s(n)$ (where $s[n]$ is the number of diagonals at each vertex), as an example corresponding to this category. However, it is quite interesting to note that Balacheff does not give an explicit reason as to why this represents a generic example (see Balacheff, 1988, pp. 224–225). Knuth and Elliot (1998), who used Balacheff's framework of proofs to provide possible student justifications for *power chord theorem*, also failed to provide a concrete example for generic reasoning. Thus, it seems that it is easier to define generic reasoning than it is to generate examples.

Only with the fourth and highest level of proof in Balacheff's taxonomy do students move from the practical—pragmatic justification—to the intellectual—conceptual justification. At the level of *thought experiment*, students are able to distance themselves from action and make logical deductions based only upon an awareness of the properties and the relationships characteristic of the situation. At this level, actions are internalized and dissociated from the specific examples considered. The justification is based on the use of and transformation of formalized symbolic expressions. Balacheff provides an example of thought experiment in his description of Olivier. This student asserted that "*In a polygon if you have* x *vertices there are automatically* y *diagonals from each point because in a boundary of the polygon there are two points which join it; in conclusion there are* x – *3 which are the diagonals*" (Balacheff, 1988, p. 227). Olivier was able to express the properties of a polygon by observing one specific example. Balacheff categorized all assertions showing the problem solver decontextualizing (or abstracting from specifics to form arguments) as thought experiments regardless of whether or not they were ultimately correct. It is the students' *approach* to the task of proving that he is categorizing not the validity of the outcome.

The four levels in Balacheff's taxonomy represent a hierarchy through which students are *expected* to progress as their notions of mathematical justification develop. Balacheff reasoned that students' understandings of mathematical justification are likely to proceed from the inductive toward the deductive and greater generality. Hence, those with increased mathematical maturity are most likely to be the students who generate deductive proofs. Balacheff also stressed that students will move back and forth between inductive and deductive reasoning depending on the task that they are completing. In other words, a student capable of thought experiment in one situation may regress to naïve empiricism in another.

Possible Justifications Under Balacheff's Taxonomy

Balacheff's (1988) taxonomy is one of the most popular proof schemas (Maher & Martino, 1996), as this framework describe most of the example usage done by students and is characterized by the hierarchical levels of proof (Knapp & Zandieh, 2004). As mentioned before, this taxonomy is based on an experiment in which a group of secondary school students came up with different ways of proving a given task. Hence, this provides an excellent strategy to analyze and classify both the various processes involved in generating conjectures and producing justifications, as well as the justifications themselves. Using this framework, teachers might be able to get a detailed understanding of the various types of student justifications that can be expected from students who are engaged in the mathematical tasks that require them to justify their solutions. However, in the literature, there are not many explicit examples of Balacheff's taxonomy: One can find these in Balacheff (1988) and Knuth and Elliot (1998). Even here, as mentioned before, there are no explicit examples of generic example or reasons as to why a particular example should serve as a generic example. The following sections are an effort to fill in this gap identified in the literature by providing examples of how students *might* complete proofs according to each of the four approaches: *Naïve empiricism, crucial experiment, generic example*, and *thought experiment* are provided. Three different proof tasks, which have been used by researchers in their own studies, are considered, and examples on how students might complete these proof tasks are generated. One important point to bear in mind is that in his study, Balacheff did not consider the correctness or incorrectness of the mathematical proof; rather, he considered only the approach that was used for justification.

Task #1: Prove That When You Multiply Any Three Consecutive Numbers Your Answer Will Always Be a Multiple of 6

This task is taken from Healy and Hoyles (2000).

Exemplars.

Level 1: Naïve Empiricism.

$$\begin{array}{ll} 1\times 2\times 3 = 6 & 6 = 6\times 1 \\ 2\times 3\times 4 = 24 & 24 = 6\times 4\,. \\ 3\times 4\times 5 = 60 & 60 = 6\times 10 \end{array}$$

Because these all work, when three consecutive numbers are multiplied, the answer will always be a multiple of 6.

Level 2: Crucial Experiment.

$$1\times2\times3=6 \quad 6=6\times1$$
$$2\times3\times4=24 \quad 24=6\times4 .$$
$$3\times4\times5=60 \quad 60=6\times10$$

Because these all work, one more example using a trio of larger numbers will be considered. If that works, then it must be true for every case. Using a calculator,

$$1136\times1137\times1138=1469877216$$
$$1469877216=6\times244979536$$

Because the assertion works in this case, too, whenever any three consecutive numbers are multiplied, the answer will always be a multiple of 6.

Balacheff (1988) distinguishes between crucial experiment and naïve empiricism on the basis of the student's selection of the example. Both Balacheff (p. 224) and Knuth and Elliot (1998, p. 715) note that students at the level of crucial experiment "intentionally," select an extreme case, and if the proof works for that example, they will then conclude that their conjecture is correct and the proof proved.

Level 3: Generic Example. This assertion will be tried for 8, 9, and 10, which is of the form even, odd, even.

$$8\times9\times10=720$$
$$720=6\times120$$

Six is 2×3. The factor of 2 comes from the 8 (or the 10), while the factor of 3 comes from the 9.

Now, this assertion will be tried for 9, 10, and 11, which represents the form odd, even, odd.

$$9\times10\times11=990 \quad 990=6\times165$$

The factor 2 comes from the 10, and the factor 3 comes from the 9 and $6 = 2\times3$.

So when any three consecutive numbers are multiplied, the answer is always a multiple of 6, as any three consecutive numbers will be of the form even, odd, even *or* odd, even, odd.

These examples illustrate generic reasoning because the calculations and answers are specific to the considered examples although the same reasoning would apply whatever numbers involved.

Level 4: Thought Experiment. Let n, $(n + 1)$, and $(n + 2)$ be three consecutive numbers. These numbers can take the form odd, even, odd *or* even, odd, even. Therefore, in any three consecutive numbers, there will be at least one number divisible by 2, as the factor of 2 comes from the even number. Every third number is a multiple of 3; hence, at least one of any three consecutive numbers will be divisible by 3. Because 2 and 3 are factors of 6, the product of three consecutive numbers is always a multiple of 6.

Task # 2: Provide a Means of Calculating the Number of Diagonals of a Polygon When You Know How Many Vertices It Has

This task is taken from Balacheff (1988).

Exemplars.

Level 1: Naïve Empiricism. A rectangle has four vertices and two diagonals (Figure 1).

A pentagon has five sides and five diagonals (Figure 2).

Hence, if v is even, the number of diagonals is $d = v / 2$, and if v is odd, the number of diagonals is $d = v$.

Level 2: Crucial Experiment. As *intentionality* in the selection of examples is what distinguishes crucial experiment from naïve empiricism, this task can be attempted at the level of crucial experiment in the following manner.

Let the conjecture be that the number of diagonals is equal to the number of vertices. An extreme polygon will be used to verify this conjecture. Pentagon is considered as

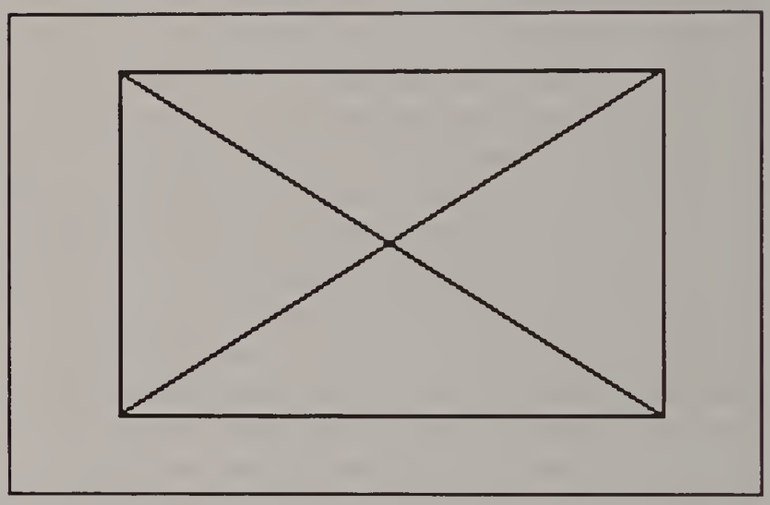

Figure 1. Vertices ($v = 4$) and diagonals ($d = 2$).

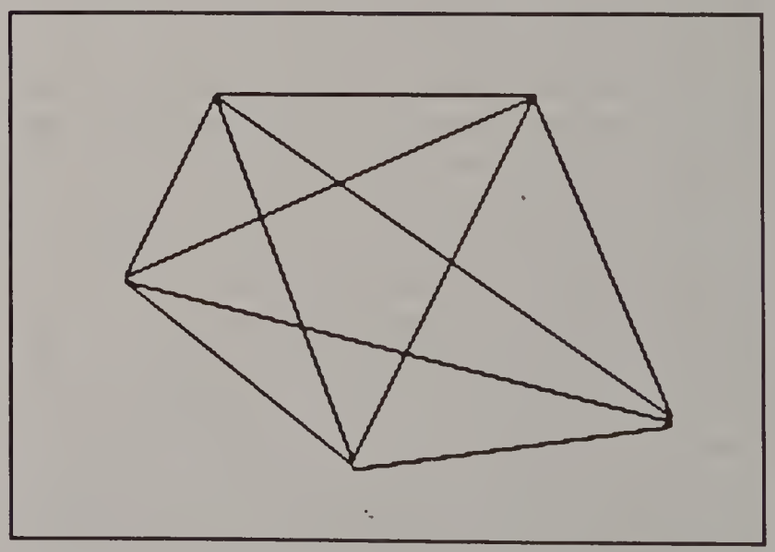

Figure 2. Vertices ($v = 5$) and diagonals ($d = 5$).

an extreme case because it is the polygon with the greatest number of sides that someone can draw with relative ease.

Refer to Figure 2. The pentagon has five sides and five diagonals.

Hence, $d = v$.

Level 3: Generic Example. Refer to Figure 2. A pentagon has five sides ($n = 5$) and so five vertices ($v = 5$). From each vertex, *only* two diagonals can be drawn as there are no diagonals from a vertex back to itself and there are no diagonals to the vertices on either side. Thus, there will be three fewer diagonals than the total number of sides (namely, two at each vertex). Because there are five sides and five vertices, a total of $5 \times 2 = 10$ diagonals can be drawn.

Diagonals have two ends; counting both ends of the same diagonal, one would arrive at a total of 10. However, we need to count only one end; therefore, the total number of possible diagonals drawn (10) should be divided by 2 to get the correct number of diagonals, which equals the number of vertices.

This exemplar illustrates generic reasoning because the calculations and answers are specific to the fact that one is considering a pentagon, although the same reasoning would apply whatever the number of sides involved. (The conjecture, of course, is false.) Arguing from the specific to the general distinguishes the generic example from the thought experiment. One of the major problems to provide a concrete example for generic reasoning in this particular task is the difficulty to find a representative polygon that will consider all the different polygons of the same number of sides and all the different polygons simultaneously.

Level 4: Thought Experiment. Consider a polygon with v sides. If there are v sides, there are v vertices. Beginning with each vertex, $(v - 3)$ diagonals are drawn (again, recall that there is no diagonal from a vertex back to itself and there are no diagonals to the vertices on either side). Thus, there will be three fewer diagonals than the total number of sides—that is, $(v - 3)$ diagonals from each vertex. As there are n sides, there will be a total of $v(v - 3)$ diagonals. As this approach counts both ends of the diagonal, one will count each diagonal twice. Hence, to get the correct number of diagonals, divide the product by 2. Therefore, the formula for the number of diagonals is $d = v(v - 3) / 2$.

Task # 3: Prove That the Sum of the Exterior Angles of a Polygon Is Always 360°

This task is taken from Varghese (2007).

Exemplars.

Level 1: Naïve Empiricism. Consider an equilateral triangle. The interior angles are 60° each. The exterior angle at each vertex is 120° each. Therefore, the sum of the exterior angles of a triangle is $120° + 120° + 120° = 360°$.

Consider a square. The interior angles are 90° each. The exterior angle at each vertex is also 90° each. The total of the exterior angle is $90° + 90° + 90° + 90° = 360°$.

Because both of these work, the sum of the exterior angles of a polygon is always 360°.

Level 2: Crucial Experiment. Consider an equilateral triangle. The interior angles are 60° each. The exterior angle at each vertex is 120°. Therefore, the sum of the exterior angles of a triangle is $120° + 120° + 120° = 360°$.

Consider a square. The interior angles are 90° each. The exterior angle at each vertex is also 90° each. The sum of the exterior angle is $90° + 90° + 90° + 90° = 360°$.

Try one more polygon, a regular hexagon. If one gets the same answer with this example, it can be concluded that the answer will always be the same. The interior angles are 120° each. The exterior angle at each vertex is 60°. Therefore, the sum of the exterior angles of a triangle is $60° + 60° + 60° + 60° + 60° + 60° = 360°$. Because all three cases worked, the sum of the exterior angles of a polygon is always 360°.

Level 3: Generic Example. Consider a triangle. Let a, b, and c represent the interior angles of a triangle: $a + b + c = 180°$. The exterior angles at each vertex will be $(180 - a)°$, $(180 - b)°$, $(180 - c)°$, respectively, as the interior and exterior angles are supplementary at each vertex. The sum of the exterior angles is $(180 - a)° + (180 - b)° + (180 - c)° = 540 - (a + b + c)°$. But $(a + b + c)° = 180°$; therefore, the sum of the exterior angles is $540° - 180° = 360°$.

OR

At each vertex, there is an interior angle and an exterior angle. The interior angle is always supplementary to an exterior angle at that vertex. Because there are three sides, the total of interior and exterior angles is $180 \times 3 = 540°$. The sum of the interior angles in a triangle is 180°. Therefore, the sum of the exterior angles is 360°.

OR

In a regular pentagon, the interior is made up of five triangles. The total of all the angles in five triangles is $180° \times 5 = 900°$. The sum of the angles of the triangles includes all the angles where the common vertex is a point in the interior of the polygon. The angles add up to 360° as they encircle a point. So the sum of the interior angles of a pentagon is $900 - 360 = 540°$.

Because there are five interior angles, there will be five exterior angles. The interior and exterior angle form a linear pair. Hence, the total of all the interior and exterior angles is $180 \times 5 = 900°$. The sum of interior angles alone

is 540°. Therefore, the sum of all the exterior angles is 900° – 540° = 360° and, hence, proved.

All of the preceding arguments are partially general within one particular class of figures (namely triangles in the first two cases and pentagons in the third case).

Level 4: Thought Experiment. Consider a convex polygon of n sides. A convex polygon of n sides can be divided into n triangles. The sum of the angles in a triangle is 180°. Therefore, the sum of the angles of n triangles in the polygon is $180n°$. The sum of the angles of the triangles includes all the angles where the common vertex is a point in the interior of the polygon. The angles add up to 360° as they encircle a point. So the sum of the interior angles of a polygon is $180n° - 360°$.

An exterior angle of a polygon is the angle formed by the side of a polygon and an extended adjacent side. The exterior angle and the corresponding interior angle together form a linear pair; hence, the sum of all the interior angles with all the exterior angles is $180n$. (At each vertex, there is an interior angle and an exterior angle. The interior angle is always supplementary to an exterior angle at that vertex.) There are n vertices as the polygon is of n sides. Hence, the total of all the interior and exterior angles is $180n°$.

$$\text{Sum of interior angles} + \text{Sum of exterior angles} = 180n°.$$

$$\text{Sum of interior angles} = 180n° - 360°.$$

Hence, the sum of all the exterior angles is $180n° - (180n° - 360°) = 360°$. And so it is *proved* that the sum of the exterior angles of a polygon is always 360°.

Summary

The role of the teacher in the mathematics classroom is to provide the foundation that will enable each student to develop increasingly more sophisticated proficiency with mathematics. The teacher can best fulfill this role if s/he understands mathematical concepts well enough to be able to identify when and how students are simply "not getting it." Within the current context of reform—a context in which teachers are expected to support their students in achieving those standards set out by the NCTM (2000)—it is critical that teachers develop a comprehensive understanding of their students' proving skills. They can do so by developing two vital skills: First, identifying the individual student's skill level at solving proof, and second, leading that student toward higher levels of mathematical reasoning. In this article, Balacheff's taxonomy of mathematical proof is presented as a developmental model, for three different proof tasks with varying difficulties, a model which, if applied to the teachers' own teaching practices, may offer considerable assistance to those who seek ways to maximize their efforts when teaching concepts and skills involved with mathematical proof. If the student justifications can be viewed through the Balacheff's (1988) framework, teachers might get a better understanding of the various types of student justifications they get from students who are engaged in mathematical tasks that require them to justify their solutions. By analyzing the student's abilities and efforts from this framework, teachers may be able to assess more efficiently and accurately student understanding at the entry level and move students more effectively and successfully toward and through each hierarchical level described in the framework.

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The Effect of Robotics Competitions on High School Students' Attitudes Toward Science

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This study was designed to examine the impact of participating in an after-school robotics competition on high school students' attitudes toward science. Specifically, this study used the Test of Science-Related Attitude to measure students' social implications of science, normality of scientists, attitude toward scientific inquiry, adoption of scientific attitudes, enjoyment of science lessons, leisure interest in science, and career interest in science. Results indicated that students who participated in a robotic competition had a more positive attitude toward science and science-related areas in four of the seven categories examined: social implications of science, normality of scientists, attitude toward scientific inquiry, and adoption of scientific attitudes. Implications of results on students' attitudes are discussed.

The robotics program examined in this study is designed to increase student interest in science, technology, engineering, and mathematics (STEM), and to increase interest in pursuing STEM-related fields. The robotics program is called the FIRST (For Inspiration and Recognition of Science and Technology) Robotics Competition. FIRST is designed to inspire students in science, mathematics, and technology by combining engineering and technology into a real-world, project-based learning experience (Kamen, 2006). The key component of the robotics program is a six-week period where teams of high school students design and build a robot designed for a specific task. Teams of 12–20 students work with a high school teacher and mentors from local universities, professional organization, and/or businesses to build a robot they can use to compete against other teams from across the United States.

In this study, a sample of high school students who participated in the FIRST Robotics Competition was compared with a sample of students from the same schools who did not participate in the program. Students' attitudes were measured both before and after the six-week design and build period in order to examine the impact of the FIRST Robotics Competition on students' attitudes toward science. The study was designed to answer the following research question:

> Do high school students who participate in the FIRST Robotics Competition have a more positive attitude toward science with respect to the social implications of science, perception of scientists as individuals, attitude toward scientific inquiry, affinity toward new scientific idea, enjoyment of science classes, science-related hobbies, and career interests in science-related fields after the six-week competition build season?

Background Literature

FIRST is a nonprofit multinational organization located in Manchester, New Hampshire. The driving goal of FIRST is to make science, mathematics, engineering, and technology as "cool for kids as sports are today" (FIRST, *About FIRST*, 2006). FIRST has several programs ranging from the Lego League for elementary students, the FIRST Tech Challenge for junior high and high school students, and the FIRST Robotics Competition designed exclusively for high school students ages 14 and above. The FIRST Robotics Competition, which was examined in this study, is designed to build awareness and interest in science and engineering in high school students and to provide them with challenging and engaging learning opportunities (FIRST, *About FIRST*, 2006).

The goal of FIRST is to create a world in which young people "dream of becoming science and technology heroes" (FIRST, *About FIRST*, 2006, np). When FIRST was founded more than a decade ago, it was modeled to emulate professional sports in America. The goal was to inspire young people to pursue careers in science and technology in the same way professional sports inspires young people to pursue careers as professional athletes (FIRST, *About FIRST*, 2006). FIRST uses marketing and media techniques to motivate students who want to learn about science and technology. The FIRST Robotics Competition was patterned after MIT Professor Woodie Flowers's engineering design course. Flowers, who acts as a national advisor to FIRST, believes that the key to the competition is that "it celebrates the efforts that came before the actual competition, as well as the gracious professionalism displayed at the competition; and the kids know that we still accept them even if their robots don't work" (Bowden, 1998).

Each team, typically consisting of 10–25 students plus technical mentors and faculty advisors, has just six weeks to design and build a robot for the given task out of a common set of basic parts. They must follow rules limiting the size, weight, and cost of their robots. Typically, the robots weigh between 100 and 120 pounds. The goal of the robot, or the "game" as it is described, changes each year and in not announced until the worldwide "Kick-Off" event the first Saturday in January (FIRST, *FIRST Robotics Team Information*, 2006).

Following the six-week build period, the robots are shipped to regional events, usually held at university arenas. The regional events involve between 40 and 70 teams and last two and a half days. The world championship is held in late April in Atlanta (FIRST, *FIRST Robotics Team Information*, 2006).

There are empirical studies, which show that project-based learning environments, like FIRST, can have a positive impact on student achievement in science and mathematics. A three-year study conducted in British secondary schools found significant differences in both student understanding and academic achievement in mathematics based on standardized test scores as a result of their participation in project-based schools (Boaler, 1999). The study found that three times as many students enrolled in the project-based schools earned the highest possible grade on the national examination in mathematics (Boaler). A similar study found that after project-based learning activities were used, eighth graders in Union City, New Jersey, scored 27 percentage points higher than students from other urban school districts on statewide tests in reading, math, and writing achievement (Honey & Henriquez, 1996). This is significant given that four years prior to the implementation of project-based learning activities, the state had considered a takeover of the school because it had failed 40 of 52 indicators of school effectiveness (Honey & Henriquez).

Theoretical Background

Through the use of hands-on, real-life, problem-solving challenges, FIRST embodies the ideals of constructivism and project-based learning. Theoretically, the program is based on a constructivist learning as conceptualized by Jean Piaget and social views of learning as conceptualized by Lev Vygotsky. According to Piaget, students possess an innate need to understand how the world operates and to find order, structure, and predictability in their existence (Eggen & Kauchak, 2001; Piaget, 1952, 1959). According to Piaget, students are motivated by a need to understand the world and use adaptive schemes of assimilation and accommodation to organize knowledge into schemes. Experience with the physical world is critical to the formation of schemes and is found in most classrooms in the form of "hands-on" activities (Ball, 1992; Hartnett & Gelman, 1998). Piaget also emphasized the role of social experience in the learner (DeVries, 1997). It is critical that the learners be allowed to test their findings against those of others. This serves as a balancing effect and motivates the learners to adapt new schemes and compare views with those of others (DeVries; Eggen & Kauchak).

While Piaget examined the impact of experience, Vygotsky theorized that participation in social activities was vital to learning (Bredo, 1997; Eggen & Kauchak, 2001; Vygotsky, 1978). Vygotsky believed that learning occurs when students gain specific understanding and development progresses when this understanding is incorporated into a larger, more complex social context (Vygotsky). FIRST is designed to capitalize on the constructivist and social aspects of learning by providing students a real-world problem they must solve as a team.

The use of inquiry-based instructional strategies in the classroom does some present challenges. Teachers may be ill-prepared to implement the activities because they lack understanding of the strategy. According to Barron et al. (1998), they must become facilitators of the learning process rather than feeding the students the information. Some teachers do not align the project with national, state, and local standards, thus creating additional challenges of accountability of learning. In addition, evaluation of academic performance is at times problematic because individual contribution during project may be difficult to assess (Blumenfeld et al., 1991).

Student Attitudes in Science

Constructivism and project-based learning are also important factors in student attitudes and motivation. Motivation is considered one of the most significant determinants of students' success or failure in the classroom (Hidi & Harackiewicz, 2000; Reeve, 1996; Ryan & Connell, 1989). Studies have shown that active involvement in learning activities is more motivating than being passive involvement (Zahorik, 1996). In addition, student control and responsibility are also associated with increased motivation, which translates into increased learning and retention of information (Eggen & Kauchak, 2001; Lepper & Hoddell, 1989).

In the 1990s, studies were conducted using select groups of students, such as at-risk, urban, or those with various disabilities. One such study highlighted the difficulties of engaging African American students who live in relative poverty when they lack motivation to learn and attend class sporadically (Tobin, Seiler, & Walls, 1999).

Motivation was also the subject of a study by Dicintio and Gee (1999). They found that their test group of at-risk students was unmotivated to learn, defiant in learning situations, and evidenced a negative attitude toward school (p. 234). They concluded that "educators and researchers working with at-risk students should be encouraged to try current, innovative, cognitively based methods of motivating students . . . [and that] at-risk students need to learn the skills of self-determination and adaptive motivation in school learning—characteristics that cannot be imparted through motivational practices that control and coerce students" (Dicintio & Gee, p. 235).

Studies have examined the relationship of attitude and achievement in the sciences. Student attitude toward science has been shown to correlate with achievement in the science classroom (Germann, 1988; Napier & Riley, 1985). In 1986, Schibeci and Riley studied the relationship between students' background, perceptions, attitudes, and achievement. Their study showed that gender is related to attitudes and achievement with females scoring lower on both. In 1990, Hill, Pettus, and Hedin found a lack of interest in science careers and lack of participation in science-related activities outside of school with middle and high school girls.

Previous Studies on the FIRST Robotics Competition

While the previous studies on the impact of the FIRST Robotics Competition did not use the Test of Science-Related Attitude (TOSRA), they do show similar outcomes as a result of student participation in the program. In 1998, Atlantic Associates reported on students' attitudes and skills as affected by FIRST Robotics. Their survey included not only students participating in FIRST, but also parents of the students, school personnel, and cooperate partners involved with the teams. The results showed that all vested parties in the program saw positive impact on students' problem-solving ability, teamwork skills, self-confidence, and attitudes toward careers in engineering (Atlantic Associates, 1998).

The Goodman Research Group conducted a survey of the FIRST teams during the 2000 FIRST Robotics Competition season. This survey used pre- and post-data with 3,123 students participating from 150 FIRST teams responding to the pre-survey and 400 responding to the post-survey. Even though the response rate was only 13%, the evaluation did provide a foundation for understanding the background of student participants, attitudes, and interest in science and mathematics, and interest in pursuing engineering careers (Goodman Research Group). According to the results of the survey, FIRST attracts boys and girls of all different grade levels with each group having different levels of interest and commitment to science, technology, engineering, and mathematics. While the results showed little change between most responses, it did show that "students decided to participate in the FIRST Robotics Competition mostly for academic reasons. They sought a challenging and educational science and mathematics experience and they expected that the experience would help them get into a better college" (Goodman Research Group, 2000, p. 52). Pre- and post-survey analysis also showed statistically significant increases in participants' attitudes toward teamwork and positive self-image (Goodman Research Group).

Brandeis University conducted a longitudinal study of the impact of the FIRST Robotics Competition on participants. The final report, *More than Robots: An Evaluation of the FIRST Robotics Competition Participant and Institutional Impacts*, was published in April 2005. The major finding of the study reveals that the FIRST Robotics Competition "does appear to be successful in meeting the goals of promoting a positive academic trajectory for its students and a sustaining interest in science and technology-related education and careers" (Melchior, Cohen, Cutter, & Leavitt, 2005, p. 57). Nearly 90% of the alumni of the program attended college, a rate substantially above the national average. Once in college, FIRST alumni were much more likely than nonparticipants to pursue courses and careers in science and technology-related fields. Forty-one percent of FIRST participants listed engineering as their primary major, a number seven times the national average (Melchior, Cohen, Cutter, & Leavitt). FIRST alumni were also more likely to attend college full-time, to have an internship, or co-op job in their first year of college, and expected to attain some form of post-graduate degree. The study notes that while it cannot control for the initial motivation of the FIRST students, the degree to which they were already interested in science and technology, the use of the matched comparison group of students with similar background in science in high school lends credence to the conclusion that FIRST did make a difference in students' choice of college careers and that, without FIRST, they would have been less likely to go into a science or technology-related field. Although the study showed that the overall impact on individual participants was strong, the impact of FIRST on local schools was more modest. The participation in FIRST did help some schools to introduce new courses, such as robotics, and increased school spirit. The final report notes that if great school impacts are desired, then a more "deliberate, school-focused strategy may be needed" (Melchior, Cohen, Cutter, & Leavitt, 2005, p. 58).

Methods

Study Participants

This study was conducted in a large Midwestern metropolitan area. Schools included in this study were located in suburban, urban, and rural areas and included both public and private affiliations. The students in this study were from nine different high schools. All of the students from the FIRST Robotics team at each high school were invited to participate in the study. The students who agreed to participate in the study comprised the treatment group. In an effort to compare students who were as similar as possible, a comparison sample of students was composed of students from the same schools and from the same science classes as the students on the robotics teams.

A total of 132 students completed the pre-survey. Eighty students reported that they were members of robotics teams; 52 reported they were not members of a robotics team. Ninety-nine students who completed the pre-survey also completed the post-survey. Fifty-eight reported they were members of robotics teams; 41 reported they were not members of a robotics team. Students completing the post-survey represented a 74.43% participation rate. The treatment group (robotics team members) consisted of 80 participants in the pre-survey and 58 in the post-survey. The comparison group (non-robotics team members) consisted of 52 in the pre-survey and 41 in the post-survey. Table 1 provides a comparison of the two groups based on gender, race, and science class GPA.

Table 1
Demographic Analysis of Participants Shown in Percentages

Gender	FIRST Students ($N = 58$)	Non-FIRST Students ($N = 41$)
Female	36.2	53.7
Male	63.8	46.3
Total	100.0%	100.0%
Race		
American Indian	0	4.9
Asian	5.2	2.5
Black	8.6	29.3
Caucasian	81.0	63.4
Hispanic	5.2	0
Total	100.0%	100.0%
Science Class GPA		
>4.0	8.6	9.8
3.5–4.0	58.7	61.0
3.0–3.4	13.8	9.8
2.5–2.9	1.7	2.4
2.0–2.4	0	2.4
<1.9	0	2.4
Do not know	17.2	12.2
Total	100.0%	100.0%

Inferential statistics were run on the post-survey results to compare the two groups in order to determine the extent to which the two groups were comparable. The results of a one-sample Chi-square test were not significant for females, χ^2 (1, $N = 56$) = .07, $p < .01$, but were significant for males, χ^2 (1, $N = 76$) = 8.90, $p < .01$. These results show that the two groups were statistically similar with regard to the number of female students in the sample, but were not with regard to the number of male students. The results of a one-sample Chi-square test were significant for white students, χ^2 (1, $N = 94$) = 13.79, $p < .01$, however, this was not significant for non-white students, χ^2 (1, $N = 38$) = 1.68, $p < .01$. These results show that the two groups were statistically similar with regard to the number of non-white students, but were not similar with regard to white students.

An independent-sample *t*-test was conducted on FIRST and non-FIRST groups overall GPA in science classes to evaluate whether their mean was significantly different. The test was significant, $t(113) = -2.02$, $p = .99$. The students participating in FIRST (M = 2.09, $SD = .67$) reported slightly lower GPAs in science classes than students not participating in FIRST (M = 2.45, $SD = 1.21$).

An independent-sample *t*-test was conducted on FIRST and non-FIRST groups overall GPA to evaluate whether their mean was significantly different. The test was not significant, $t(118) = .182$, $p = .12$. The students participating in FIRST (M = 2.44, $SD = .86$) reported approximately the same GPA as students not participating in FIRST (M = 2.41, $SD = .81$). Therefore, the two groups appear statistically similar.

Overall, the results indicate that the two groups appear comparable. There were only two differences between the two groups. The results indicate that the treatment group had slightly more male students but had a slightly lower GPA in science classes.

Instrumentation

The TOSRA was used to assess students' attitudes toward science (Fraser, 1981). The TOSRA is designed to measure seven distinct science-related attitudes among secondary school students: Social Implications of Science, Normality of Scientists, Attitude toward Scientific Inquiry, Adoption of Scientific Attitudes, Enjoyment of Science Lessons, Leisure Interest in Science, and Career Interest in Science (Fraser, 1981). The TOSRA is designed to be used by educators and researchers to monitor student progress toward achieving attitudinal aims (Fraser, 1981). In his handbook for TOSRA, Fraser states, "TOSRA is likely to be most useful for examining the performance of groups or classes of students" (Fraser, 1981, p. 1).

Each scale on TOSRA contains 10 items, while the total instrument contains 70 items. A sample of questions from the TOSRA in listed in the appendix. The response scale is a five-point Likert scale with responses ranging from strongly agree (1) to strongly disagree (5). Within each scale, five are positive items and five are negative with respect to their position on science, and science-related issues. All items were adjusted so that the higher numeric values associated with the response categories of the items always reflected the positive side of the Likert scale indicating a more positive view of science. The coefficient alpha of .97 suggests that the TOSRA was reasonably reliable for respondents in this study. The intercorrelations of the TOSRA scales were calculated as indices of discriminate validity. The intercorrelation was low and ranged from 0.10 to 0.59 with a mean of 0.33 (Fraser, 1981).

Research Time Period

The pre-surveys were administered between mid-December and the first week of January, prior to the six-week build season. The post-surveys were administered between late February and early March, immediately following the conclusion of the six-week build season. All surveys were in administered in face-to-face format at the high schools.

Statistical Methods

Analysis of covariance (ANCOVA) based on the scale scores from the pre-survey was used for analysis and is described in detail below for each question. ANCOVA was used to adjust for differences in the nonrandomly assigned groups. In this study, ANCOVA was used to determine whether the means of the dependent variable, the post-survey, for two or more groups of the independent variable, the pre-survey, differed significantly when the influence of participation in FIRST Robotics was correlated with the dependent variable. The level of significance for each variable, the p value or probability, was analyzed for the established alpha level of 0.05. For this study, the p values less than 0.05 were considered statistically significant, which represents the critical value most commonly used in behavioral statistics. The effect size reported is partial eta square and ranged from zero to one. A zero indicates no relation between the covariate and dependent variable, while a one indicates a strong possible relationship between the variables.

Results

A comparison of the mean scores, standard deviations, p values, and effect sizes for the seven TOSRA categories is shown in Table 2.

Social Implications of Science

An analysis of the homogeneity-of-slopes assumption indicated that the relationship between the covariate and the dependent variable did not differ significantly as a function of the independent variable, $F(1, 95) = 1.53$, $MSE = 28.52$, $p = .22$, partial $\eta^2 = .02$. Therefore, the homogeneity-of-slopes test indicated that the assumption had been met and that the results of an ANCOVA would be meaningful. A comparison of the pre- and post-means indicated that students who participated in the FIRST Robotics Competition had a more positive attitude toward the social implications of science than students who did not participate in FIRST.

The FIRST participants recorded a 0.64 increase in the mean difference, whereas the non-FIRST participants recorded a –0.93 mean difference. Students in the FIRST group had statistically significant higher attitude means, ($p < 0.01$), than students in the comparison group regarding their attitude about the social implications of science as measured by the TOSRA. The strength of the relationship between the FIRST factor and the dependent variable was small, as assessed by the partial $\eta^2 = 0.08$, with the FIRST factor accounting for 8.0% of the variance of the dependent variable. This indicates that the students participating in FIRST had a greater appreciation for and more positive attitude of the importance of science and the social implications of science-related issues than the non-FIRST students because of their participation in the FIRST Robotics Competition.

Normality of Scientists

An analysis of the homogeneity-of-slopes assumption indicated that the relationship between the covariate and the dependent variable did not differ significantly as a function of the independent variable, $F(1, 95) = .43$, $MSE = 22.60$, $p = .51$, partial $\eta^2 = .01$. Therefore, the homogeneity-of-slopes test indicated that the assumption

Table 2

Mean Scores, Standard Deviations, p *Values, and Effect Sizes for the Seven TOSRA Categories*

TOSRA Category	FIRST Students		Non-FIRST Students		*p*	Effect Size*
	Pre-(N = 58)	Post-(N = 58)	Pre-(N = 41)	Post-(N = 41)		
Social implication of science	40.48	41.12	36.58	35.65	.008	.081
	(6.94)	(6.96)	(5.91)	(5.14)		
Normality of scientists	36.18	37.20	34.60	33.38	.011	.065
	(5.06)	(6.29)	(4.56)	(5.06)		
Attitude to scientific inquiry	36.75	39.24	34.50	34.63	.015	.058
	(7.69)	(7.90)	(6.61)	(6.03)		
Adoption of scientific attitudes	38.14	39.20	34.77	33.73	.004	.094
	(7.09)	(6.64)	(6.09)	(5.49)		
Enjoyment of science lessons	37.86	38.41	32.34	33.00	.096	.029
	(9.51)	(8.44)	(8.48)	(7.74)		
Leisure interest in science	33.98	35.02	26.80	28.17	.173	.019
	(9.51)	(9.27)	(6.95)	(7.42)		
Career interest in science	35.50	36.31	28.83	29.95	.116	.026
	(8.47)	(7.97)	(8.00)	(7.34)		

*Effect size is shown using partial eta square value.

had been met and that the results of an ANCOVA would be meaningful. A comparison of the pre- and post-means indicated that students who participated in the FIRST Robotics Competition had a more positive attitude toward the normality of scientists than students who did not participate in FIRST.

Students in the FIRST group had statistically significantly higher attitude means, (p = 0.011), than students in the comparison group regarding their attitude about the normality of scientists as measured by the TOSRA. The strength of relationship between the FIRST factor and the dependent variable was assessed by a partial η^2 = 0.065 with the FIRST factor accounting for 6.5% of the variance of the dependent variable.

This indicates that students participating in FIRST Robotics have a greater appreciation and more positive attitude toward scientists and members of the scientific community in general than students not participating in FIRST Robotics. During the same time, the non-FIRST students recorded a decrease in the mean. The increase in the mean of the FIRST students may be a result of their interaction with technical mentors and engineers.

Attitude to Scientific Inquiry

An analysis of the homogeneity-of-slopes assumption indicated that the relationship between the covariate and the dependent variable did not differ significantly as a function of the independent variable, $F(1, 95) = 1.25$, $MSE = 40.92$, p = .27, partial η^2 = .01. Therefore, the homogeneity-of-slopes test indicated that the assumption had been met and that the results of an ANCOVA would be meaningful. A comparison of the pre- and post-means indicated that students who participated in the FIRST Robotics Competition had a more positive attitude toward scientific inquiry than students who did not participate in FIRST.

Students in the FIRST group had statistically significantly higher attitude means, (p = 0.02), than students in the comparison group regarding their attitude toward scientific experimentation and inquiry as ways of obtaining information about the natural world and their acceptance of scientific inquiry as a way of thought, as measured by the TOSRA. The strength of relationship between the FIRST factor and the dependent variable was small, as assessed by a partial η^2 = 0.058 with the FIRST factor accounting for 5.8% of the variance of the dependent variable.

Adoption of Scientific Attitudes

An analysis of the homogeneity-of-slopes assumption indicated that the relationship between the covariate and the dependent variable did not differ significantly as a function of the independent variable, $F(1, 95) = 2.30$, $MSE = 28.85$, $p = .13$, partial $\eta^2 = .02$. Therefore, the homogeneity-of-slopes test indicated that the assumption had been met and that the results of an ANCOVA would be meaningful. A comparison of the pre- and post-means indicated that students who participated in the FIRST Robotics Competition had a more positive attitude toward the adoption of scientific attitudes than students who did not participate in FIRST.

Students in the FIRST group had statistically significantly higher attitude means, ($p < 0.05$), than students in the comparison group regarding their open-mindedness and willingness to revise opinions toward scientific experimentation and inquiry as measured by the TOSRA. The strength of relationship between the FIRST factor and the dependent variable was small, as assessed by a partial $\eta^2 = 0.094$, with the FIRST factor accounting for 9.4% of the variance of the dependent variable.

Enjoyment of Science Lessons

An analysis of the homogeneity-of-slopes assumption indicated that the relationship between the covariate and the dependent variable did not differ significantly as a function of the independent variable, $F(1, 95) = 2.93$, $MSE = 39.33$, $p = .09$, partial $\eta^2 = .03$. Therefore, the homogeneity-of-slopes test indicated that the assumption had been met and that the results of an ANCOVA would be meaningful. The ANCOVA was not significant, $F(1, 96) = 3.13$, $MSE = 40.12$, $p = .10$, showing that there was no difference between groups regarding their enjoyment of science lessons.

Leisure Interest in Science

An analysis of the homogeneity-of-slopes assumption indicated that the relationship between the covariate and the dependent variable did not differ significantly as a function of the independent variable, $F(1, 95) = .56$, $MSE = 38.47$, $p = .46$, partial $\eta^2 = .02$. Therefore, the homogeneity-of-slopes test indicated that the assumption had been met and that the results of an ANCOVA would be meaningful. The ANCOVA was not significant, $F(1, 96) = 3.17$, $MSE = 38.29$, $p = .17$, showing that there was no difference between groups regarding their participation in science-related activities.

Career Interest in Science

An analysis of the homogeneity-of-slopes assumption indicated that the relationship between the covariate and the dependent variable did not differ significantly as a function of the independent variable, $F(1, 95) = .95$, $MSE = 28.69$, $p = .33$, partial $\eta^2 = .03$. Therefore, the homogeneity-of-slopes test indicated that the assumption had been met and that the results of an ANCOVA would be meaningful. The ANCOVA was not significant, $F(1, 96) = 2.79$, $MSE = 28.67$, $p = .12$, showing that there was no difference between groups with regard to their aspirations toward careers in science.

Discussion

Statistical significance was found in four of the seven categories of the TOSRA: social implication of science, normality of scientists, attitude toward scientific inquiry, and adoption of scientific attitudes. A discussion of each of these follows. No statistical significance was found in the remaining three categories: enjoyment of science lesson, leisure interest in science, and career interest in science. These results are not unexpected given that students volunteer to be a part of the FIRST Robotics program. This creates a self-selected sample, which has already shown a propensity toward science-related activities and career aspirations in science-related fields.

The more favorable attitude of FIRST students toward the social implications of science may be the result of several factors. While participating in the six-week build period, students work directly with professionals to design, build, and test their team's robot. For many team members, this is the first time they have had the opportunity to experiment outside the classroom and to actually apply skills learned in the classroom. Students must work together toward a common goal; using the engineering design process, they work with mentors from local engineering companies and universities to create a robot for the specific task. It is during this time that science becomes "real" and not just "words in a book."

The results of this study indicate that participants in FIRST view scientist as more "normal" than students who do not participate in FIRST, yet the FIRST students' view of normal includes descriptions such as "geek." This indicates not only a shift in viewpoint toward scientists, but also a shift in the vernacular among FIRST participants. While the general public often uses "geek" in a pejorative context, FIRST students have adopted the term "geek" to represent a position of status and honor, of which they strive to be a part.

Some of the explanation can also be found in the working relationship that is developed during the build season with the technical mentor, many of whom are engineers, who volunteer to work with the teams. For many students, this is their first interaction with scientists and

engineers and the close relationship that is built influences their perceptions of the profession. Many students who participate in FIRST discover that the terms "geek" and "nerd" do not apply to these individuals; they perceive them as "cool" and "hip."

The Oxford English Dictionary (OED) defines "geek" as "a simpleton, a dupe, a person who is socially inept or boringly conventional or studious." The Urban Dictionary agrees with the OED definition of "geek" but also adds that in modern usage, the term "enjoys special status within the technical community," and that it ". . . indicates a recognition that most people still consider programming computers to be a bizarre act, along a certain fierce satisfaction in being very good at their inglorious profession." The term "geek" often carries a positive connotation when used by a member of the group.

Perhaps the explanation for the increase in attitude toward scientific inquiry by students participating in the FIRST Robotics Competition relates to the notion that the competition is built around the foundation of experimentation and inquiry. The focus of the FIRST Robotics Competition is the six-week build season in which teams have six weeks to complete the task of designing, building, testing, and shipping their robots. The six-week build season begins with the "Kick-Off." On the first Saturday of January, the "challenge" is presented via a simultaneous NASA broadcast from FIRST Headquarters in New Hampshire. It is during this broadcast that students discover the challenge and specifics about the rules. They are also introduced to that year's kit of parts (the basic building components all teams start with for the competition). Following the broadcasts, teams meet to begin the brainstorming process and to gather the necessary information to best approach their solution to the challenge. The following weeks are filled with design meetings, building prototypes, construction of the robot, testing, redesigning, and finally, shipment of the finished robot to a regional event. It is during these six weeks that the students work as much as possible, often well into the night and weekends. This is when the students actually apply the science and mathematics they learn in the classroom and when they work most closely with the technical mentors.

The ability to be open-minded and willing to reverse opinions is vital to members of FIRST Robotics teams. During the design process, teams usually develop multiple plans and must select the best one based on their ability to build it and their available resources. This is often the most challenging time for the students, as each wants their design to be selected. Students must learn to negotiate and be willing to accept the ideas of other team members. An example of this was found with a local FIRST Robotics team who had to make a formal presentation of their design to a doctoral candidate who works in biped robotics and served as the team's technical mentor. During this presentation, which also included other teachers and parents, the students had to answer questions from their mentor regarding various issues of force, torque, power, and other engineering principles. The students had to negotiate their opinions with his expertise. At the end of the evening, both were satisfied and the team proceeded with a slightly modified design, which went on to earn "Highest Rookie Seed" at a regional competition. This would not have been possible if the students had not been willing to alter their original plans and listen to the technical mentors.

The study has important implications for the field of science education. The results imply that programs that engage students in authentic scientific problems can significantly improve students' attitudes and views of science. The FIRST program appears to be helping students develop a more positive attitude and interest in science. Positive views toward science are often viewed as an important correlate to achievement in science, and as a result, programs like FIRST that can help improve students' attitudes and interest in science may be an important part of helping students achieve in science. The positive attitudes and interest may also lead to future careers in science-related fields, but more research will be needed to better understand the long-term impact of the program on students.

The importance of this study to science teachers is that it suggests the program is working in terms of the vision of FIRST ". . . to transform our culture into one that values science and technology and encourages young people to pursue education and careers in science and technology" (Kamen, 2006). The findings of this study suggest that students participating in FIRST Robotics have more positive attitudes and interests in science than students not participating in the program. The positive attitudes and interest may lead to higher academic achievement and future careers in science-related fields, but more research will be needed to better understand the long-term impact of the program on students.

Recommendations for Further Research

The long-term vision of FIRST to foster interest in science, mathematics, and technology and to increase the number of students enrolled in science and technology programs in colleges and universities can only be evaluated in a longitudinal study encompassing a greater population.

Current and former FIRST team members should be included in such a study. This study should be conducted tracking individual students through each year of participation of a FIRST Robotics team and into their post-secondary activities, such as college, university, or trade school education, military service, or employment.

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Appendix

Sample Questions

Q1 "Money spent on science is well worth spending."

Q3 "I would prefer to find out why something happens by doing an experiment than by being told."

Q9 "Scientists are about as fit and healthy as other people."

Q15 "Public money spent on science in the last few years has been used wisely."

Q16 "Scientists do not have enough time to spend with their families."

Q45 "I would rather solve a problem by doing an experiment than be told the answer."

Q46 "In science experiments, I like to use new methods which I have not used before."

Q59 "I would prefer to do an experiment on a topic than to read about it in science magazines."

Q60 "In science experiments, I report unexpected results as well as expected ones."

Q64 "Money used on scientific projects is wasted."

BioMusic in the Classroom: Interdisciplinary Elementary Science and Music Curriculum Development

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Policymakers and industry leaders are calling for a 21st century education that is more interdisciplinary in nature, including the ability to solve problems and think creatively (PTCS, 2004). Traditional teaching practices that present subjects as separate and distinct disciplines do not encourage students to make connections between subjects in school and in the inherently interdisciplinary nature of their daily lives. It is important for educators to help students link multiple subjects with the world outside the classroom (Katz & McGinnis, 1999), encouraging reform that implements a multidisciplinary approach and real world applications. Boix Mansilla, Miller, and Gardner (2000) describe interdisciplinary learning as integrating concepts from two or more disciplines to establish an understanding that moves beyond the scope of one discipline. It follows that rich inquiry is often achieved by taking multiple perspectives and multiple approaches to examining a science topic (AAAS, 2006).

The goal of transitioning emerging research and development into a classroom-ready form requires collaboration between scientists, researchers, and teachers. As a member of Partnership for 21st Century Skills, the North Carolina Department of Public Instruction has defined goals for helping students become "future ready" (NC Framework for Change, 2008). This term refers to preparing students to think creatively and solve problems, which are targeted by the Partnership for 21st Century Skills (PTCS, 2004) and other policy organizations as essential to life and work in contemporary society. It follows that there is recognition of the need to shift pedagogical approaches beyond simply preparing students either to become future scientists or to pass standardized tests (Millar & Osborne, 1998) and move toward developing scientific literacy among all students (AAAS, 2006). Innovative curriculum, especially when it encourages productive interdisciplinary experiences (Barab & Landa, 1997; Brandt, 1991), can engage students in ways that help them see science directly connected to their daily lives.

With these goals in mind it is important to recognize that students' lives are not divided into discipline areas, yet disciplines are traditionally presented separately in school. Efforts to include true interdisciplinary experiences in today's schools face many obstacles: teachers as subject specialists, class time schedules, traditional school structures limiting teacher time for curriculum development or collaboration, and lack of understanding of interdisciplinary learning (King & Wiseman, 2001). Rather than true interdisciplinary experiences, students usually participate instead in *thematic* or *multi*disciplinary approaches. In a case study that explored an interdisciplinary approach to history and visual arts, Dawes and Boix Mansilla (2007) described how interdisciplinary instruction should integrate domains, creating a new understanding. The typical structure of a school day hinders these natural connections and discourages blending concepts. In elementary schools, where there is potential for flexibility in scheduling, teachers still most often divide their instruction of subjects into separate time slots. When teachers specialize in a particular field, they may hesitate to expand from the comfort zone of their field of specialization. Crow and Ponder (2000) suggest restructuring teacher involvement in multiple disciplines by promoting teacher teams—bringing together teachers with different areas of specialization and exposing one another to new content knowledge and instructional approaches.

The present article describes a study that examined the experiences of a teacher team: two elementary school teachers, a music teacher and a science teacher, as they developed and implemented innovative, interdisciplinary curriculum based around BioMusic. This emerging field of research combines physical and biological sciences of sound and animal communication with concepts from the discipline of music. Through BioMusic, this project involved designing curricula to provide opportunities for elementary school students to gain a deeper understanding of their world, expanding beyond the traditional classroom presentation of music and the physical properties of sound. Authentic interdisciplinary connections link value to content (Barab & Landa, 1997; Brown, Collins, & Duguid, 1989), in this case through science and music relationships. The approach taken by this project to develop interdisciplinary curricula encountered the challenges of

interdisciplinary work and points to strategies that can nurture and support the important goal of interdisciplinary practice by teachers and experiences by students.

Background for the Study

Science Instruction

There are many challenges in science education, especially at the elementary school level. Marx and Harris (2006) recognized the role of NCLB in developing the culture of standardized tests, which ultimately limited science time and impeded implementation of project-based science curricula. Important efforts in maintaining our nation's leadership in science and technology should begin in elementary school (Bybee, 2007). The National Science Foundation has called for diversifying the pool of talented students entering the STEM pipeline as well as cultivating students' capacity for interdisciplinary exploration (Langen & Dekkers, 2005). Interdisciplinary approaches for including science in elementary school classrooms and maintaining the natural connections between science and other subject areas, including music, can address some of these challenges. It is also important for students to have a broad range of science thinking skills, including work with multimodal data sources. For example, students should have experience with auditory information and re-representing it using, for example, physical models, drawings, words, and musical notations (Barrett, 1997; Britsch, 2009; Harrison & Treagust, 1998; Shepardson & Britsch, 2001; Minogue, Wiebe, Madden, Bedward, & Carter, 2010).

Music Instruction

The National Association for Music Education promotes curriculum design in grades K-12 that helps students understand connections between music and other disciplines (Music Educators National Conference, 1994), but these connections are often superficial and consist of using the repetition of songs to help students memorize facts (Wiggins, 2001). Further, Wiggins warns that integration of music with other disciplines needs to consider the integrity of each of the disciplines in order to be conducted wisely.

Music instruction at the elementary school level includes helping students learn about melody, rhythm, timbre, and harmony, along with finding patterns and tones. Unfortunately, music is often taught in isolation from other disciplines. In a similar vein, content from physical and life sciences have traditionally been taught separately at the elementary school level, yet the natural connections between the physics of sound and the sounds in nature link these two areas of science and science with music.

Interdisciplinary Connections of Science and Music

Interdisciplinary connections were initially promoted as a model for educating children with special needs, however the interdisciplinary approach has become recognized as effective with all students (Welch, et al., 1992). Many school districts in North America support interdisciplinary curricula to address the cognitive, cultural, developmental, motivational, and stylistic diversities of students (Barab & Landa, 1997). Howard Gardner's (1983) work on multiple intelligences offers further support for instructional approaches designed to meet the needs of students who possess various strengths and challenges. Every classroom has students with a wide variety of ability levels and preferred learning modalities whose learning is enhanced when teachers illustrate natural, multimodal connections among concepts.

Applebee, Burroughs, and Cruz (2000) identify a continuum of possibilities when teachers move from traditional, discipline-based instruction to either integrated or interdisciplinary approaches. These range from specialist teachers serving the same group of students but maintaining their independent curricula to teams planning together to create totally new curricular domain, expanding the contributing subject areas, such as BioMusic.

This expansion of subjects aligns with the National Science Teachers Association goals that promote new, creative approaches to curriculum integration with engaging application to students' lives. For example, the two disciplines of science and music can be connected in schools when teaching about sound. Science curriculum often focuses on the physics of sound including the source of sound, the path of sound, the medium through which sound travels, and how sound is received by humans. Music curriculum typically focuses on the quality of various sounds along with traditional Western instruments and songs. Recent research in the biological connections of music and science (Gray, et al., 2001) provide new opportunities for student learning.

BioMusic and UBEATS

Interdisciplinary teaching and learning are promoted to meet the increasing demand for interdisciplinary reasoning in the 21st century (Boix Mansilla, 2010). Interdisciplinary experiences for teachers and for students are, as outlined above, important in elementary education. However, creating curricula through this process can be a challenging proposition. Inevitably, this process involves give and take among its participants and an evolving understanding and appreciation for other theoretical, professional practice, and disciplinary lens on the topics and activities being developed. The Universal BioMusic Achievement Tier in

Science (UBEATS) project attempted an interdisciplinary curriculum development project, understanding the challenges that would need to be overcome.

Underlying the UBEATS project is BioMusic, an emerging field of interdisciplinary research that explores the commonalities of musical sounds and time found among species and explores the deep structures and relationships of pitch, phrasing, rhythm, and volume that affect species' roles in biodiversity (Gray, et al., 2001). In addition to humans, some other species studied include whales, birds, mice, and elephants, among others. The interests of BioMusic researchers are varied and span both an interdisciplinary and trans-disciplinary context, including biology, neuroscience, ethnomusicology and bioacoustics.

The UBEATS project is a curriculum development effort designed to promote an awareness of BioMusic concepts for elementary school students. An overarching goal of this project is to enable teachers and their students to explore their aural world as a learning resource for new science and music curriculum based on the standards of both disciplines. This part of the project examines the curriculum development process and pilot testing to expose students to both physical sciences of sound (e.g., animal frequency ranges) and connections of music in the biological world (e.g., bird songs, whale songs). Two teacher partners, an elementary music resource teacher and a science resource teacher, collaborated with the UBEATS science and music education project team leaders. Research scientists working in the emerging field of BioMusic shared their research during initial training and made themselves available as consultants during the project.

The present project began with an initial introduction to the innovative field of BioMusic, followed by the development of lessons designed to explore the connections of science and music in the natural world. The lessons were pilot-tested with elementary school students in both science and music classrooms. Researchers examined how the interdisciplinary curriculum writing and implementation process impacted a music teacher's and a science teacher's evolving perceptions of hers and her partner's discipline. We explored how the curriculum development process impacted their perception of interdisciplinary instruction, and we focused on the challenges they faced as they became familiar with BioMusic content, wrote lessons, and implemented interdisciplinary instruction. The goal here is to present a study that addresses a void in the research literature on teacher teams at the elementary level and provide additional evidence on interdisciplinary teaching approaches.

Research Questions

The research questions evolved as the process unfolded. Hatch (2002) supports the evolving research question development based on data as it is collected. During this study we sought to investigate the science and music teacher partners' teaming efforts to develop curriculum that presented both the physical sciences of sound and music along with the biological component of music in nature. The research questions for the present project focused on the curriculum writing process of the teachers and their interactions with material from their own discipline and the complementary discipline. Our initial question was, "How do teachers' newly gained knowledge of BioMusic impact teaching and learning in the classrooms of the music and science teachers?" As the study progressed, more focused questions developed. These questions asked:

1) How did the teachers' perceptions of their discipline and their partner's discipline evolve throughout the curriculum writing and implementation process for each teacher?

2) How did the curriculum writing and implementation process impact their image of interdisciplinary instruction?

3) What are some of the challenges of the interdisciplinary curriculum development and implementation process?

Method

A case study method was used to examine the two teachers' curriculum development of this innovative field of research. Yin (2009) supports the case study design for explanatory investigations. Because the two teachers worked closely in the project, they are presented as a team rather than individually. We analyzed data simultaneously with data collection (Hatch, 2002), which guided further observations and interviews for the study. We conducted three interviews with each teacher along with collecting field notes during a total of 19 observations as the teachers piloted the lessons with their students. In addition, we collected copies of both the lesson plans created by the teachers and student work (i.e., student notebooks). Inductive analysis was used to find patterns of themes that emerged from the data (Glasser & Strauss, 1967; Hatch, 2002), which included interviews, field notes, and artifacts (Denzin & Lincoln, 2000). The field notes and interviews were coded to correlate with research questions and identified as relevant in the development or implementation of the interdisciplinary curriculum.

Recruitment of Participants and Setting

The two-person team of teacher partners was recruited to participate in the project through a teacher enhancement fellowship program. Pseudonyms are used for the two teachers in the present case study. Both of the teachers were experienced teachers. "Denise" has been an elementary school teacher for 12 years and for the last four years she has been the science specialist at her school. "Clara" has taught music in various grade levels for 15 years, spending the last 9 years as a music teacher in elementary school. Both of the teachers were drawn to their current school because it is a "creative arts and sciences" magnet school that emphasizes Gardner's multiple intelligences.

Table 1 summarizes the timeline of the project.

During the first summer (2008) the two teachers were immersed in multiple training experiences on topics such as guidance in leadership and training in curriculum writing strategies. As part of the UBEATS project, the two teachers spent two weeks learning from researchers who specialize in a wide range of BioMusic fields. Researchers who study bird songs, whale songs, the effect of music on the human brain and body (neuroscience), ethnomusicology, and bioacoustics were among the presenters. Teachers in this project capitalized on connections with the BioMusic researchers who were both scientists and/or musicians, willing to foster cross-disciplinary thinking while providing research materials and connections to field research. We examined the two teachers as they planned the format and guiding questions for their lessons; then they developed the lesson drafts, working both together and individually.

Data Collection and Analysis

Hatch (2002) described qualitative data analyses as a "systematic search for meaning" (p. 48) with the recognition that the researchers engage their own understandings as they attempt to make sense of data. The music and science teachers' curriculum development, revisions, and implementation are described here and are presented as a cross-case analysis (Yin, 2009). The data include interviews, field notes from observations of pilot testing of the lessons, student notebooks and drafts of the lessons themselves.

The initial interviews with the teachers took place at the beginning of the first summer. We conducted a second interview two months later as the teachers began writing the upper elementary learning modules as a team at the start of the school year. The third interview took place at the end of the fall as they completed pilot testing the lessons with their upper elementary school students. During the first interview (see Appendix A) we followed a general interview format (Patton, 1990), but as the interviews progressed we implemented improvisational scripting (LeCompte & Preissle, 1993). The following section is organized by the research questions with related data.

Table 1
Project Timeline

Summer 2008	• Research team begin planning meetings • Research team and teachers meet • Teachers and researchers immersed in BioMusic content Presentations by BioMusic scientists • Teacher teams begin initial draft of modules
Fall 2008	• Teachers complete draft of 4/5 module • Research team provides feedback on module • Teachers use feedback and revise 4/5 module • Teachers begin writing 2/3 module
Winter 2008	• Pilot testing of 4/5 modules respectively in 4th grade science and music classes • Mentors observe lessons and collect field notes and artifacts • Teachers collect notes during 4/5 lessons and incorporate them into revisions • Teachers complete 2/3 module draft
Spring 2009	• Pilot testing of 2/3 modules by team teaching in 2nd grade class • Mentors observe lessons and collect field notes and artifacts • Teachers collect notes during 2/3 lessons and incorporate them into revisions • Teachers incorporate their revisions and those of BioMusic scientists and research team in both modules

Results

Research Question 1—Evolution of Perspectives on Disciplines

- How did the teachers' perceptions of their discipline and their partner's discipline evolve throughout the curriculum writing and implementation process for each teacher?

During the initial interviews, both teachers described their learning process as they were becoming immersed in interdisciplinary BioMusic concepts. When asked about her comfort teaching science, Denise responded, "I feel comfortable teaching science, but I think the content area for me of BioMusic is the topic that I'm still working toward getting a better understanding of." Clara described her comfort teaching music, but shared Denise's discomfort in learning to combine science and music in the BioMusic content. Denise explained, "This was an area that was new, and even though we do sound in physical science, connecting it with life science is the different part of it but one that the kids really seem to like." Anderson et al. (1994) described the complex learning curve that is required when teachers adapt new curricula. Teachers need to connect new material and concepts to their existing understandings. The field of BioMusic is an innovative area of study, requiring teachers and researchers to expand and even reevaluate their existing views of science and music connections.

Regarding their comfort with the complementary field, both expressed a need to learn more about the material. Clara felt unsure about science because she described herself as "not an outdoorsy person" and recognized that she needed to broaden her perspectives to try to see how science and music relate to each other. Denise added:

> I am definitely learning a lot about music. I actually caught myself thinking sometimes when I hear a sound, how it would look when I'm looking for sonograms for the kids and also trying to use the music vocabulary in the lesson. Making those connections with the kids and not coming from a music background, that's a stretch.

Both teachers initially viewed their disciplines through a somewhat traditional lens. Working on the UBEATS project expanded their views: Denise explored sounds in nature, going beyond traditional lessons on vibrations and sound. Carla allowed students to express music using nontraditional notations and identify songs and sound patterns in the natural world, and both teachers learned concepts and vocabulary of BioMusic.

In summary, (1) Each used their existing discipline to bridge into BioMusic: Denise went from physics of sound to biological basis of sound while Clara expanded her view from traditional representation of Western music. (2) Both teachers acknowledged the learning curve required with the complementary field and with the emerging field of BioMusic.

Research Question 2—Interdisciplinary Instruction

- How did the process impact their image of interdisciplinary instruction?

Both teachers were able to elaborate on changes in their images of interdisciplinary instruction, especially relevant coming from a school that focuses on subject area relationships. During the first interview, Clara felt that the curriculum development process with her science partner ". . . brought me insight on similarities between my curriculum and the science field." Denise described her need to learn "all the terms [in music] and where they're found and just the whole color behind music." The importance of learning the complementary terminology, the vocabulary used in their partner's field, was a theme repeated by both teachers during the interviews.

The second interview that took place at the end of the grade 4/5 pilot testing revealed further explorations of the interdisciplinary relationship of music and sound. When we asked Denise how her students would benefit from the interdisciplinary connections, she responded:

> I know it will help them make connections because when we talk about the science of music and where music is, some students said music is the wind, or music is animals or water dripping and they were talking about just environmental sounds and it was very enlightening.

Field notes regarding interdisciplinary connections described one science class when the students walked around their schoolyard with recording equipment to record the sounds of nature. The following music class built upon this experience. Clara played their recordings for the groups to remind them of their walks, she showed them spectrographs of the sounds, and students drew pictures and words to graphically represent the experience. Embedded in these discussions were music terms of "tempo" and "rhythm" as well as "patterns of vibrations," showing students' interactions with music terms and the science of sound.

Because the teachers developed the lessons together, they were aware of the content in both classes. The shared

writing process and paired implementation supported a flow of concepts between classes and both expressed an increased awareness of the other's discipline. Clara felt that she was "certainly thinking more about science now" and she described the students as excited about the connections. She described her impression as coming from a multiple intelligences perspective, saying that the lessons "bring science-centered kids to music and music-centered kids to science."

Field notes recorded during our observations in Denise's science class described a day when she reminded the students of their work in Clara's class earlier in the week, exploring sounds as vibrations using percussion instruments. Denise had various centers set up to allow students to experience vibrations with wax paper kazoos, tuning forks and their vibrations' impact on salt or water. One student excitedly raised his hand and exclaimed, "I see a connection!" She asked him to explain, and he described the connections between the explorations of vibrations with musical instruments in Clara's class and the recordings of various animal songs during science centers. This incident revealed one student's recognition of a relation between science and music concepts. A neo-Piagetian tradition suggests that an initial understanding of each concept in isolation is necessary before connections between two concepts can be understood (Boix Mansilla, 2010). The developing understanding of science and music concepts and their integration were indicated for the teacher participants as well as the students.

During the pilot testing of the 4/5 modules in the fall, each teacher presented the UBEATS lessons in her own classroom. The lessons were written with the intent that any classroom teacher whether a generalist, music, or science specialist would be comfortable presenting it to his or her students; however, both teachers in the study described greater comfort in teaching their own specialty area. As a result, they decided to teach the 2/3 modules as a team during the pilot testing the following spring. This required coordination from their principal, the classroom teachers, and other specialist teachers, but it was important enough to them to make the arrangements. This effort illustrated the slow transition in their interdisciplinary thinking, especially significant that their comfort zones remained intact even as curriculum developers. It was clear both from the interviews and observations that the two teachers were challenged to expand their visions of the interdisciplinary connections of science and music beyond the physical relationship of science and music to include the biological relationships of sound.

At this point, neither teacher seemed to completely internalize Boix Mansilla, Miller, and Gardner's (2000) definition that interdisciplinary instruction should produce an understanding going beyond the scope of each discipline. Both teachers' knowledge expanded during the process, but they still seemed to maintain their views of "connections" between disciplines rather than developing new understandings beyond their respective disciplines. Yet, by the third interview, both teachers discussed the interdisciplinary concepts of patterns and pitches of animal songs that they used to design inquiry opportunities for students to explore animal behaviors and related song frequencies and rhythms.

In summary, (1) Collaborating as colleagues and teaching a common interdisciplinary curriculum are two different things (the latter is harder). (2) Interdisciplinary work helped drive home commonalities in concepts being taught as well as emphasizing the need to understand the unique connections.

Research Question 3—Challenges of Curriculum Development

- What are some of the challenges of curriculum development and implementation?

Time was identified by each teacher as a challenge, both for the paired writing process and finding time to include the lessons in their existing program. When we asked Clara if she felt confident that the curricular materials would be easily adapted to her school schedule she expressed hesitations. "I do, as long as it's aligned." We asked her to clarify:

> My concerns are with the national and state standards . . . so as long as they are aligned I feel like there will be time to include the lessons.

Denise shared the concerns about whether their lessons met state and national standards:

> We definitely want it to be based on objectives and that was a little bit tricky too because it fit well with certain state standards so we're looking at ways to adjust the goals to more of the national standards.

Another challenge was the use of technology to record and illustrate sound images of animal songs, connecting music to biology and physical science. Computers were used to access various animal sounds from the Internet and also to access the BioMusic project's Wild Music website. Various animal songs were translated into spectrograms, showing students a visual representation of the

sounds, illustrating patterns and pitch. These graphical representations allowed students to incorporate their visual and aural interpretations of the music in nature, expanding from music and science to the interdisciplinary field of BioMusic.

Field notes included descriptions of various incidents where LCD projectors failed to work, preventing students from viewing the spectrograms along with hearing the recorded sounds. Other times the students could not hear the recorded sounds on the computer because they lacked external speakers. The availability of technology in classrooms has lagged sorely behind the use of technology in much of our society, but with the rapid expansion of technology options, the availability in schools will increase. It is important to prepare students with 21st Century Skills (PTCS, 2004), the multi-dimensional abilities that include information, media, and technology skills.

In addition to technology challenges, structured school schedules discouraged time for teacher collaboration and curriculum development, and both teachers in this study described the time challenge with their interdisciplinary efforts. The pressure to align with standards related to the time constraints with expectations to address standards that may conflict with innovative interdisciplinary approaches. During this study, the teachers' periodic challenges using technology only added to the time pressures and further inhibited instructional efforts to innovatively illustrate the relationships in nature's sounds.

In summary, (1) Time was a challenge in lesson development and implementation. (2) Alignment with standards was a crucial component for teachers to accept the material, and (3) Technology access and implementation challenged the flow of implementation.

Discussion

This case study describes the efforts of two teachers, one music specialist and one science specialist, involved in the UBEATS-BioMusic curriculum development project. The project was designed to promote interdisciplinary connections of music with the physical sciences of sound and the biological relationships of sounds in nature, with an underlying goal of helping students develop science literacy across disciplines. Our research questions focused on the teachers' initial views of their own and their partner's discipline, and we explored their evolving views throughout the curriculum development and implementation process. Another research goal was to identify the challenges they faced throughout the process. The music and science specialists entered the project confident of their field and ability to develop connections; however, they struggled both intellectually and logistically with the connections between their field and with presenting BioMusic as an interdisciplinary concept. The teachers' challenges to meet their goals of interdisciplinary instruction illustrate the difficulties with adapting new curricula.

The UBEATS project is aimed at developing elementary science curricula that will eventually reach classrooms across the nation. Regardless of the excitement of emerging research in science and music, research often does not have a natural flow into the classroom. For teachers, change requires restructuring teachers' beliefs and can be a slow process (Davis, 2002; Tobin, Briscoe & Holman, 1990). Anderson et al., (1994) describe the process for teachers to adapt new curricula as framed in constructivist learning theory, proceeding through an adaptation process that includes active involvement in content and pedagogical construction of meaning. In addition, teachers must connect their new understandings with the learning community. All of this involves adaptation and change of traditional teaching practices, in this case promoting interdisciplinary instruction. As indicated in the first interviews conducted at the start of the first summer, the two teachers entered the project confident in their curriculum development abilities, but as the project developed, their beliefs about their field and that of their partner were challenged as they explored connections in their respective disciplines. Their efforts to fully embrace BioMusic as an interdisciplinary field of its own were expressed in the interviews. Further, even as authors of the curriculum who wrote and implemented the lessons during pilot testing, they struggled with recognition of full interdisciplinary application.

Squire, MaKinster, Barrnett, Luehman, & Barab (2003) suggest that teachers should develop or adapt their own materials rather than inherit university-developed curriculum. The paired recruitment of teachers in the present study allowed the teachers to share the writing process, so they were able to claim ownership of the materials rather than attempt to implement lessons written by others. Maintaining the goal of promoting inquiry opportunities for students, curricula needs to be designed that will be used by teachers in the context of their classrooms.

Researchers in this study found differences in the teachers' approaches toward implementing innovation. During our observations it became apparent that Clara was more resistant to straying from the existing music curriculum and to adopting pedagogical approaches such as the use of science notebooks. Both teachers described their difficulties of learning vocabulary of the their partner's field and of BioMusic concepts. Nikitina and Boix Mansilla (2003)

examined integration of mathematics and science in pre-collegiate programs and described specialized knowledge and vocabulary as obstacles to interdisciplinary goals, leading teachers to emphasize singular facts over broad concepts. As teachers change their views of disciplinary instruction they need support in integrating and wielding this new vocabulary and knowledge.

One of the key components necessary to effect change is teacher acceptance of new concepts and strategies. Teachers' beliefs regarding a teacher's role in the classroom, beliefs about how students learn and about the attitudes toward curriculum impact their inclination to implement new curricula. Connelly & Ben-Peretz (1980) conducted a study that documented teachers' need to find its value as necessary before they make the choice to implement the curriculum.

Clara expressed concerns about the new materials fitting into the standards based requirements of the music and science curricula (Byo, 1999), which she felt would indicate that the material would be included in standardized testing. Harlen (1999) recognized that high-stakes testing inevitably impacts what is taught. Implementing reform-minded classroom practices in the atmosphere of school accountability and high-stakes testing face many obstacles. When new science instruction programs are not perceived to match state science education guidelines and correspond to mandated examinations, teachers and administrators may be reluctant to spend time teaching material that does not appear on tests, regardless of their value (Moreno, 1999). The UBEATS team emphasized the importance of this alignment, and review of the final written modules revealed that the lessons included both national and state science and music standards.

Implications

Lessons from the present study highlight considerations that are necessary in order for interdisciplinary reform efforts to become a reality. Interdisciplinary connections should be more easily implemented in elementary school than middle or high school; however, a number of obstacles remain. The emphasis on standards-based high-stakes testing has resulted in diluted curricula at all levels, including elementary schools (Amrein & Berliner, 2002). The pressure for teachers to focus on tested subjects and only tested topics within those subjects has watered down curriculum across the United States and impedes efforts to provide students with opportunities for science inquiry and exploration. For new research to filter into schools, teachers need support from administrators, researchers, and parents, among others. Support includes time for professional development for learning new material, planning, and collaborating with researchers and other teachers. An acknowledgment of standards alignment and technology support will also benefit education reform, justifying teachers' perceptions of interdisciplinary curriculum as meeting multiple discipline and standards-based goals rather than "fitting in" to their already full school schedules.

In the present study, BioMusic scientists offered support by providing content, materials, feedback, and their time. More scientists need to devote their time and effort for science education reform (Crosby, 1997). Effective interdisciplinary instruction can provide opportunities for students to build 21st century skills and developing science literacy across disciplines. Breaking down the subject area barriers can contribute toward reform, allowing teachers to help sharpen students' connections with the natural world.

The process of applying developing research ideas to elementary school classrooms requires collaboration between research scientists, project leadership teams, and innovative elementary school teachers. In this study, it was important to ensure that the interdisciplinary curriculum addressed the science and music education goals that are important in the context of public schools. The connection between the disciplines of music and science challenge the traditional separate subject area compartments found in many schools. Music and science face the additional challenge in elementary education of often being assigned subordinate roles with little time allocated. The implementation of innovative and interdisciplinary curriculum in elementary school is a collaborative process, which requires administrative support, infrastructure support, and a willingness to explore new ways of knowing (Driver, Asoko, Leach, Mortimer, & Scott, 1994).

Future Goals

New teams of teachers will be added to this project to develop more modules that incorporate BioMusic content and processes for elementary school students. Each lesson will be introduced to more teachers and students, refining and improving the lessons with each iteration and examining student learning. There is tremendous potential for expanding lessons covering a wide range of BioMusic research. In addition to studying the various animal species, other lessons will focus on the BioMusic scientists' research design and the applicable science processes.

Barab & Luehmann (2003) describe a central goal of curriculum development to design lessons that are flexible

enough to allow teachers to adapt the curriculum to their circumstances and local needs. They also recognize that, "True reform is a collaborative process and involves working with teachers as partners" (p. 464).

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Appendix A: Interview Questions

1. What do you feel is your greatest area of need in learning more about your specialty field (music or science)?
2. What do you feel is your greatest area of need in learning more about your teaching partner's specialty field (music or science)?
3. How comfortable are you with the curriculum writing process?
4. What is the greatest challenge you face in the writing process?
5. Do you feel confident that the curricular materials you develop for this project will be easily adapted to your school schedule?
6. Do you see any obstacles that would hinder incorporating these materials in the Fall? If so, what?
7. What value do you feel the music/science interdisciplinary connections will offer your students?
8. How much assistance will you need in learning about the complementary curriculum of this project?
9. Do you feel that you will develop appropriate comfort with the materials this summer to feel you can teach it to students this fall?
10. Do you feel that you will be able to share these materials and offer support to fellow teachers?

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PROBLEMS section

Ted Eisenberg, *Section Editor*

This section of the Journal offers readers an opportunity to exchange interesting mathematical problems and solutions. Please send them to Ted Eisenberg, Department of Mathematics, Ben-Gurion University, Beer-Sheva, Israel or fax to: 972-86-477-648. Questions concerning proposals and/or solutions can be sent via e-mail to eisenbt@013.net. Solutions to previously stated problems can be seen at http://www.ssma.org/publications.

Solutions to the problems stated in this issue should be posted before February 15, 2012

• **5182:** *Proposed by Kenneth Korbin, New York, NY*

Part I: An isosceles right triangle has perimeter P and its Morley triangle has perimeter x. Find these perimeters if $P = x + 1$.

Part II: An isosceles right triangle has area K and its Morley triangle has area y. Find these areas if $K = y + 1$.

• **5183:** *Proposed by Kenneth Korbin, New York, NY*

A convex pentagon ABCDE, with integer length sides, is inscribed in a circle with diameter $\overline{AE}$.

Find the minimum possible perimeter of this pentagon.

• **5184:** *Proposed by Neculai Stanciu, Buzău, Romania*

If x, y, and z are positive real numbers, then prove that,

$$\frac{(x+y)(y+z)(z+x)}{(x+y+z)(xy+yz+zx)} \geq \frac{8}{9}.$$

• **5185:** *Proposed by José Luis Díaz-Barrero, Barcelona, Spain*

Calculate, without using a computer, the value of,

$$\sin\left[\arctan\left(\frac{1}{3}\right)+\arctan\left(\frac{1}{5}\right)+\arctan\left(\frac{1}{7}\right)+\arctan\left(\frac{1}{11}\right)+\arctan\left(\frac{1}{13}\right)+\arctan\left(\frac{111}{121}\right)\right].$$

• **5186:** *Proposed by John Nord, Spokane, WA*

Find k so that, $\int_0^k \left(-\frac{b}{a}x+b\right)^n dx = \frac{1}{2}\int_0^a \left(-\frac{b}{a}x+b\right)^n dx$.

• **5187:** *Proposed by Ovidiu Furdui, Cluj, Romania*

Let f: $[0,1] \to (0, \infty)$ be a continuous function. Find the value of,

$$\lim_{n\to\infty}\left(\frac{\sqrt[n]{f\left(\frac{1}{n}\right)}+\sqrt[n]{f\left(\frac{2}{n}\right)}+\cdots+\sqrt[n]{f\left(\frac{n}{n}\right)}}{n}\right)^n.$$

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i. Percent Paid *(15c divided by 15f times 100)*			97.15	97.09

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☑ If the publication is a general publication, publication of this statement is required. Will be printed in the December 2011 issue of this publication. ☐ Publication not required.

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PS Form **3526,** September 2006

SSM Publication Guidelines

Journal Office:
Stephanie Harrison, Editorial Assistant
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Reader: K-graduate leaders and teacher educators
Frequency of issue: 8 times per year
Copies per issue: 3001-4000
Sponsorship: Professional organization

Publication Guidelines:
Manuscript length, 6-26 pages including references. In addition, up to 5 pages of tables/figures/appendices will be acceptable. Tables/figures should fit on no more than one page each.

Review Information:
Type of review: Blind review
No. of external reviewers: Three
No. of in-house reviewers: One
Time to review: 6-7 months
Acceptance rate: 20%
Reviewers' comments are returned to the author

Manuscript Topics:

Science, mathematics, and connections between science and mathematics for grades K-graduate and teacher education, especially science and mathematics articles that deal with assessment, attitudes, beliefs, curriculum, equity, research, translating research into practice, learning theory, alternative conceptions, philosophy and history of science, sociocultural issues, special populations, technology, nontraditional forms of instruction, and science/technology/society.

Manuscript Guidelines/Comments:

Submit your manuscript through the ScholarOne site. You will need to register at the site and follow the instructions.

The lead author must be a member of the School Science and Mathematics Association to submit the article and must remain a member in good standing at the time of publication of the paper. Membership information can be found at the Association web site www.ssma.org.

Manuscript Preparation:

All manuscripts must be prepared according to the 6th Edition of the *Publication Manual of the American Psychological Association*. Submissions that are not APA style, or exceed the length limitation, or lack any of the following components will be returned for correction and not reviewed.

1. An abstract not to exceed 200 words on a separate page.
2. Typed double-spaced manuscript using a 12-point or larger font, with 1″ margins top, bottom, and sides. Manuscript should be limited to 25 pages for text and references. Up to 5 additional pages total will be allowed for figures, tables, and appendices.
3. To maintain anonymity, DO NOT include a cover page with author information. In the manuscript, author(s) citing their own work should cite as follows: In text: Author (2007) found… On reference list: Author (2007). *Journal Title.* (Do not include title of article or volume and page #)
4. Graphics should be black type on white background. Do not use color in graphs or figures. Follow APA guidelines for table and figure format and titles. Each table or figure should be on a separate page at the end of the manuscript, with a note within the manuscript where the graphic should be placed. Use no smaller than 8-point font for text on figures; use no smaller than 11-point font for tables. Figures and tables should be no wider than 6.75 inches.
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All manuscripts are subject to a review process. Manuscripts should not have been previously published nor be under consideration for publication in any other journal.

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The manuscript will first be evaluated for fit with the journal guidelines, alignment with APA, and topic alignment with priorities of the journal. The Editor will reject manuscripts that do not adhere to these criteria without review.

Review Criteria:

The following criteria will be used by reviewers in evaluating the appropriateness of manuscripts for publication in *School Science and Mathematics:*

- Relevant, timely, and significant
- Addresses K-graduate science or mathematics education issues
- Explicit, clear, logical, concise
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- Problem/Research Questions
- Theoretical Framework/Literature Review
- Design/Instrumentation/Procedure
- Data Analysis/Results
- Discussion/Conclusions
- Written presentation/style
- Adds new knowledge

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